



Spatially Explicit Evapotranspiration Mapping for Large Scale Agro- Hydrologic Applications

Gabriel Senay
USGS EROS

April Webinar Organized by the
National Soil Survey Center
Tuesday, April 22nd, 2014, 1:00 – 2:00 PM Central Time

Outline

- Summary
- Background and justification
- ET Products (drought monitoring and early warning)
 - MODIS (operational)
 - Landsat based ET
- Conclusions

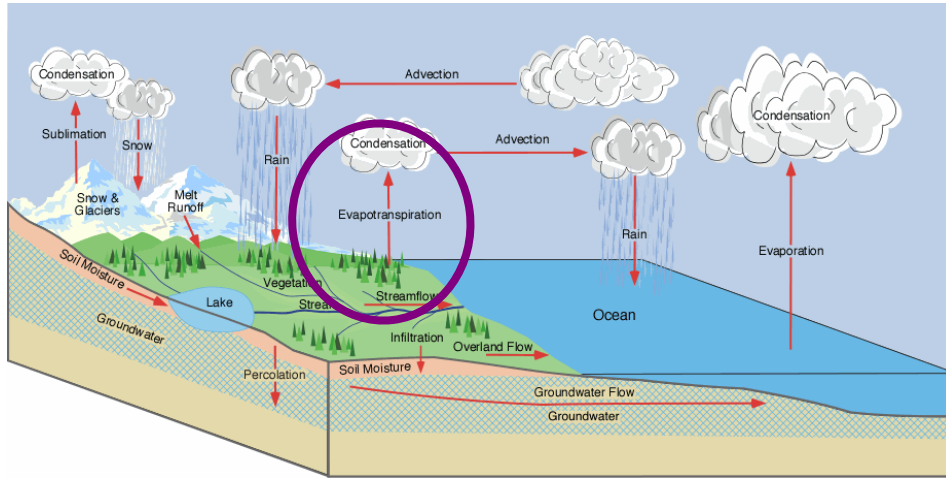


Summary

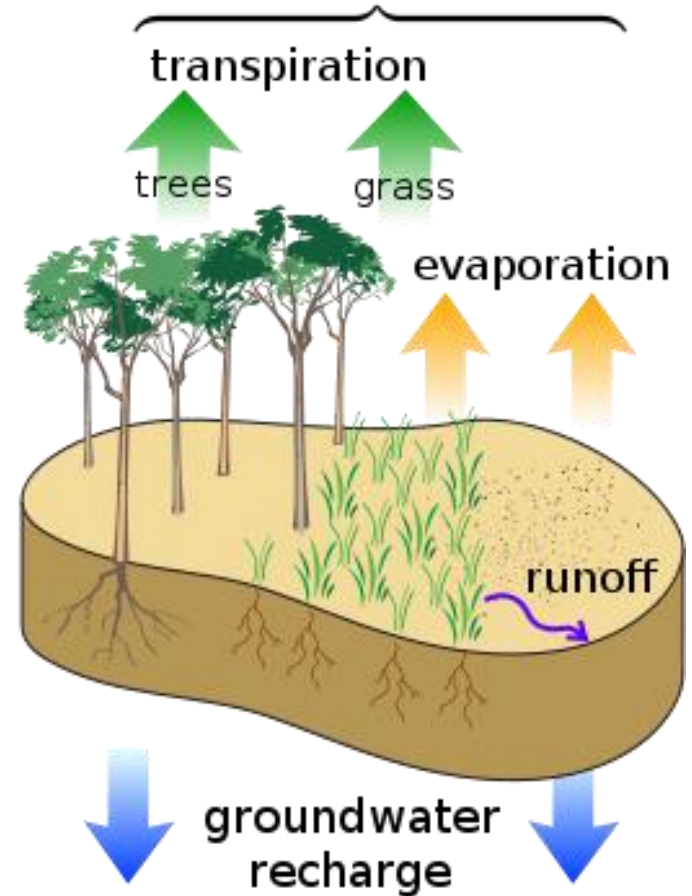
- Satellite-based ET can be estimated operationally using Land Surface Temperature (LST) as the main driver.
- Applications for drought monitoring is reliable as is.
- Applications for water balance studies require calibration with local measurements for bias removal.



Hydrologic cycle



evapotranspiration =
transpiration + evaporation



Remote Sensing ET Research and Application Funded by:

USGS Groundwater Program

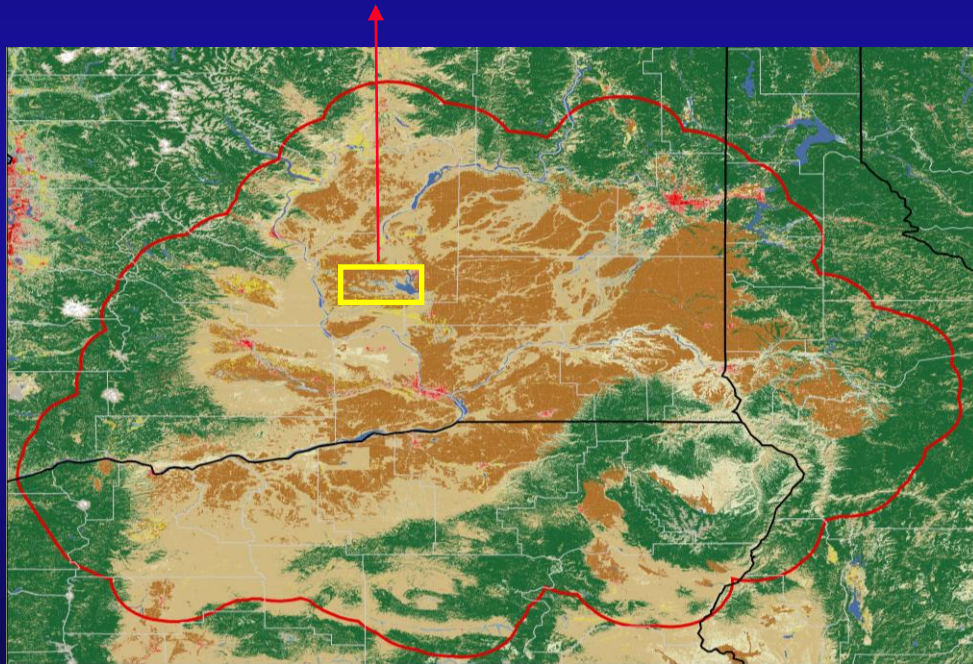
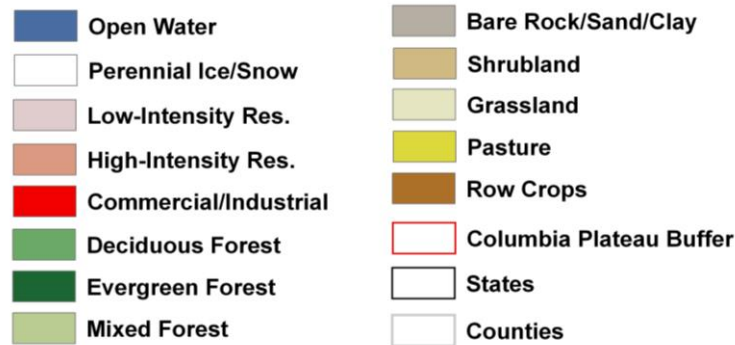
USAID FEWS NET

WaterSMART/USGS Water Census



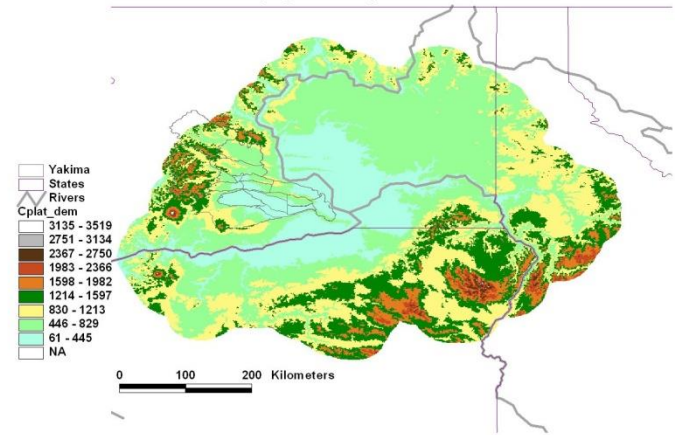
Columbia Plateau Groundwater Availability Study

center pivot irrigation



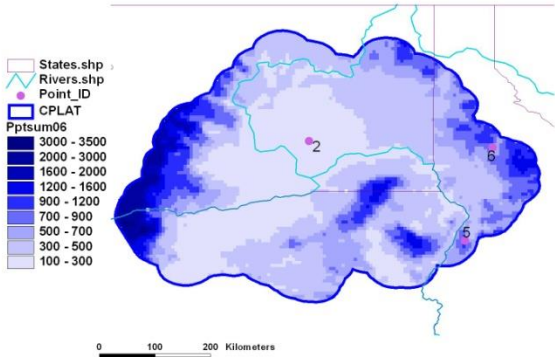
NLCD 2001

Digital Elevation Model (m)
(Hydro1K)

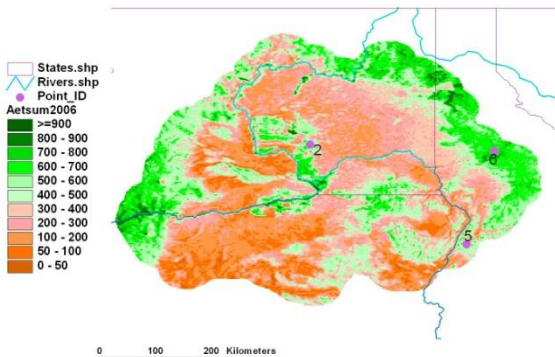


Annual Water Balance

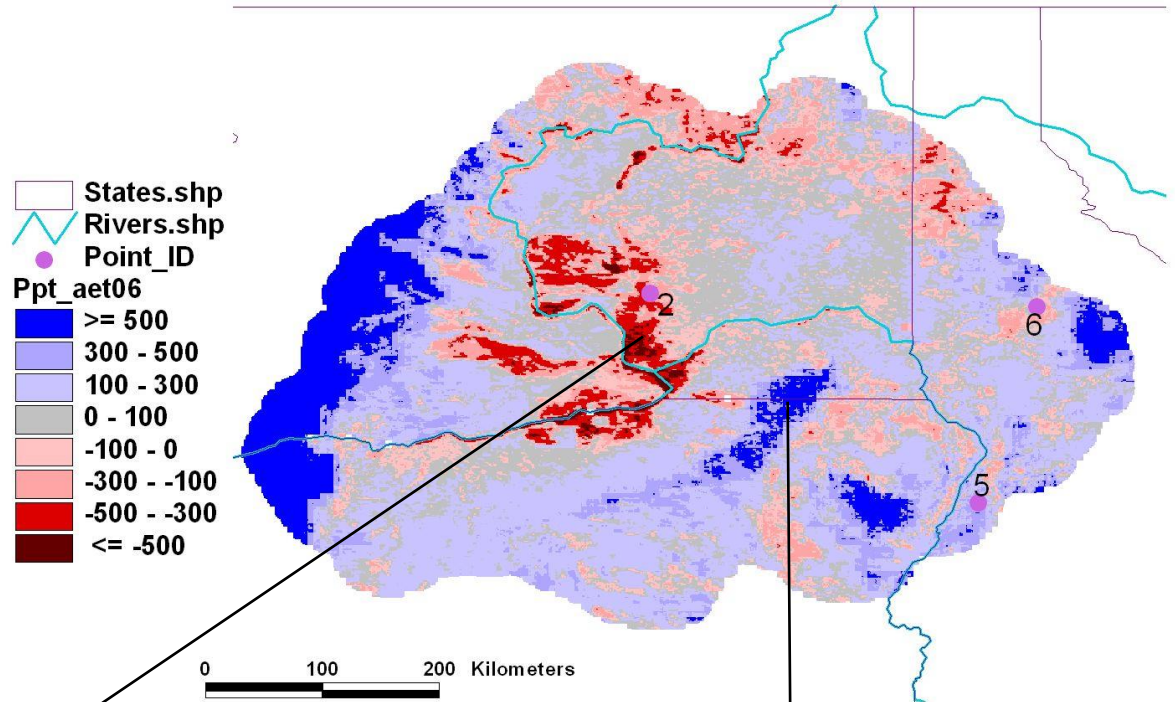
2006 Annual Precipitation (mm)
(NOAA/NEXRAD)



2006 Annual ETa (mm)
Columbia Plateau: SSEB, Jan - Dec



2006 Annual Water Balance (PPT - ETa) (mm)
Columbia Plateau: NOAA/NEXRAD Precip minus SSEB ETa)

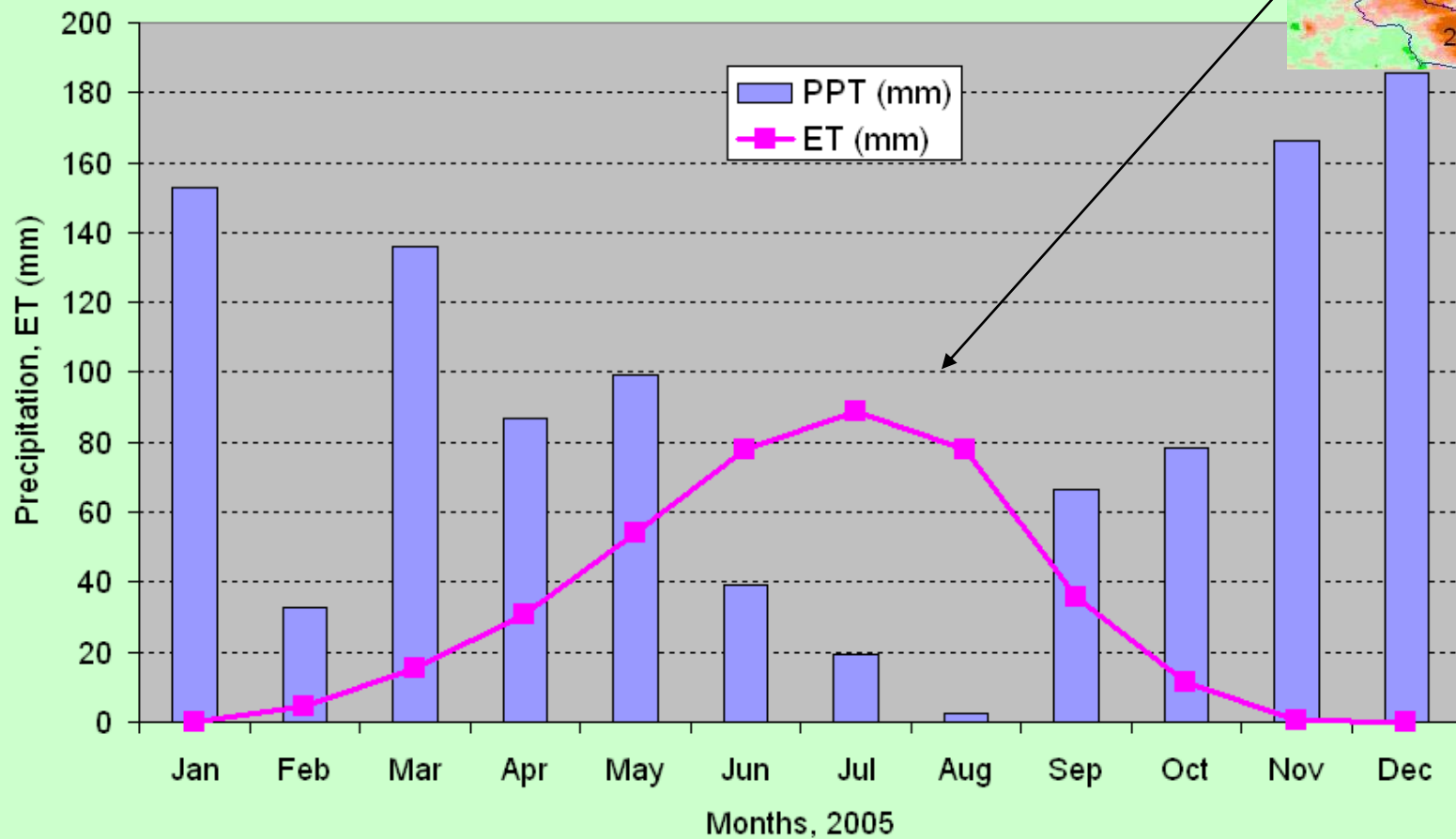


Withdrawal

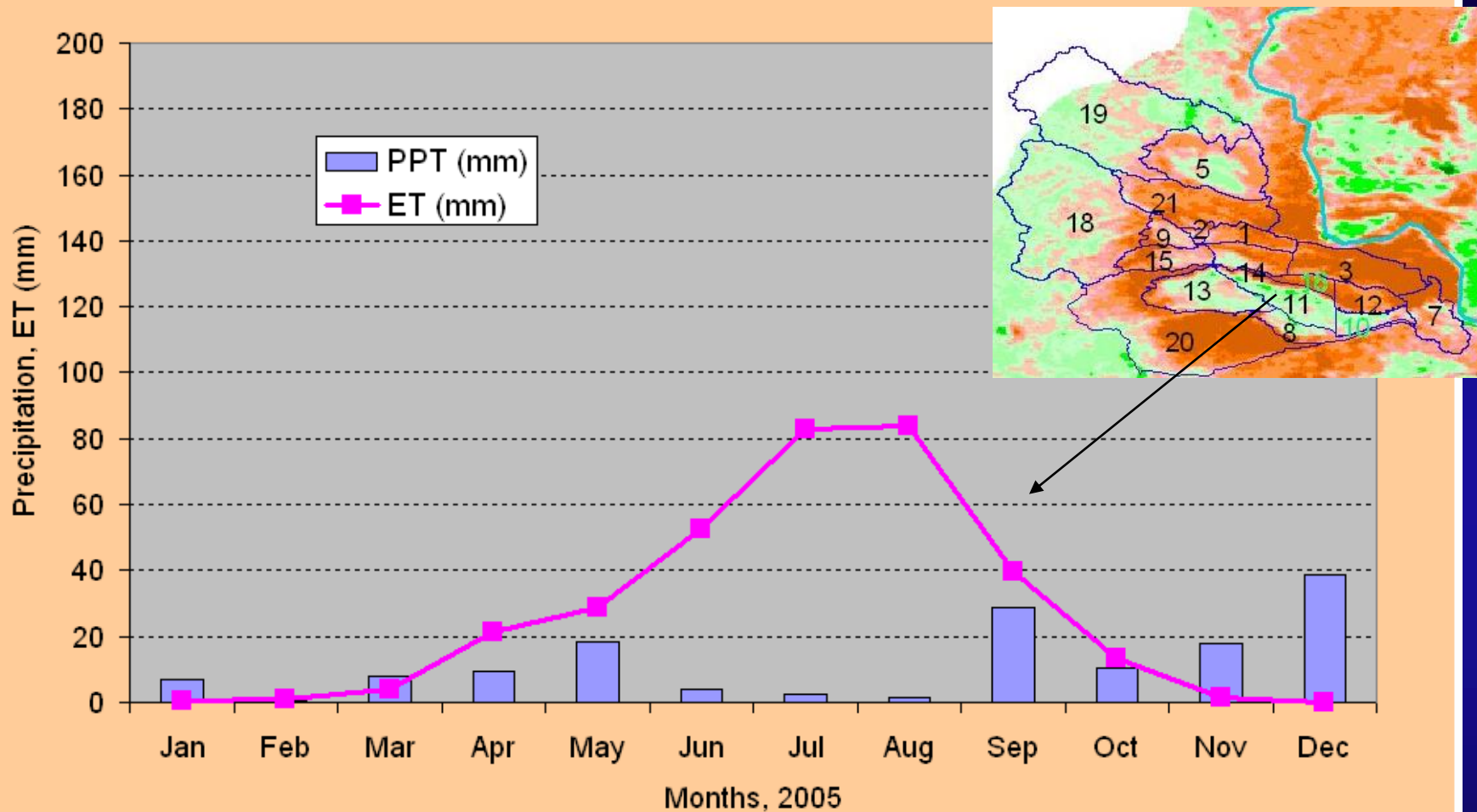
Recharge



Monthly Traces of Precipitation and ET for 2005 Rainfed Basin, ID 18



Monthly Patterns of Precipitation and ET for 2005 Irrigated Basin, ID 11

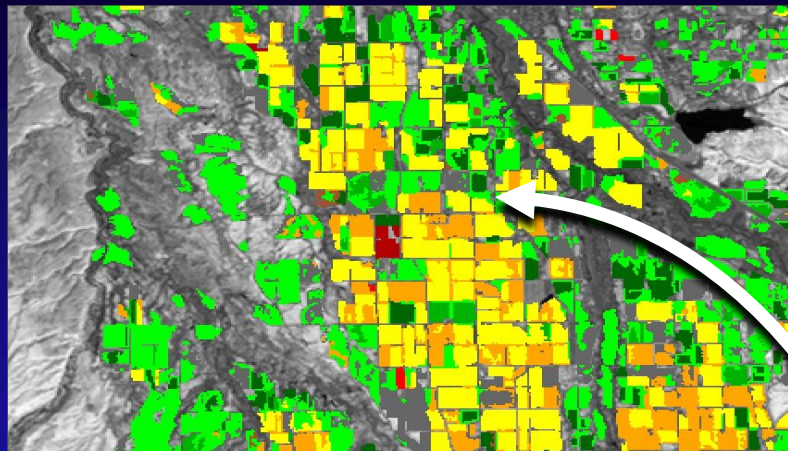


EROS WaterSMART/Water Census

- Develop/improve ET model for crop consumptive use estimation
- Apply ET model on regional and national scales for water use and water availability quantification.



Who, how much, when?

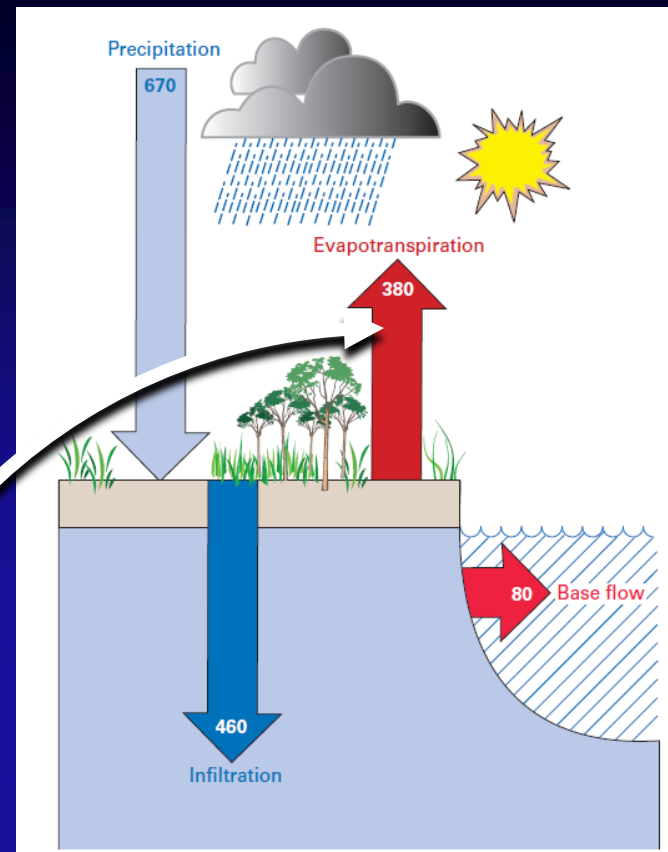


Water Use Effort:
For irrigation water use to
estimate consumptive use.

12 digit HUC
Watershed



ET



Water Budget Effort:
Total ET as a component of
the water budget.

Temporal Scale: Monthly, weekly, daily ?? Trends for how many years back ??



Role of Remote Sensing

- Land Surface Temperature (LST) from thermal imagery
 - Landsat (~100m)
 - MODIS (1km)
 - AVHRR (1km)
 - GOES (10km)
- Precipitation Estimate
 - NOAA NEXRAD (5km)
 - METEOSAT RFE (10km)
 - NASA TRMM (25 km), etc



Two Principles for ET Estimation...

- **Water Balance**
 - driven by **precipitation** accounting
- **Energy Balance**
 - driven by **Land Surface Temperature (LST)**



Which model(s) to use...

**All models are wrong but
some are useful**

(George E. P. Box, 1976)



Several Approaches...

- **Soil Moisture Modeling**

- Land Surface Models such as Noah, SWAT, VIC, **VegET...**

- **Vegetation Index based**

- NDVI/LAI-based: MOD16, P-M, P-T

- **Mixed Approach**

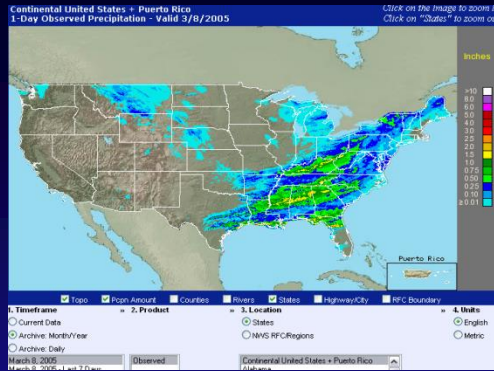
- NDVI-LST (Trapezoid, Triangle...)

- **Surface Energy Balance**

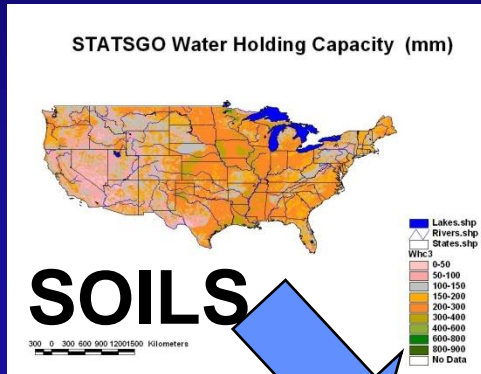
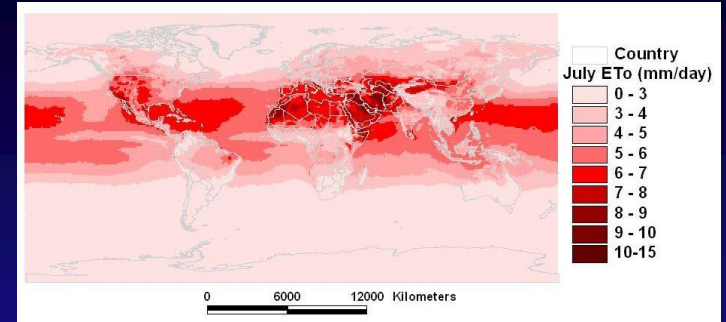
- SEBAL/METRIC, SEBS, Two-Source, ALEXI, S-SEBI, **SSEBop...**



PRECIPITATION



Reference ETo



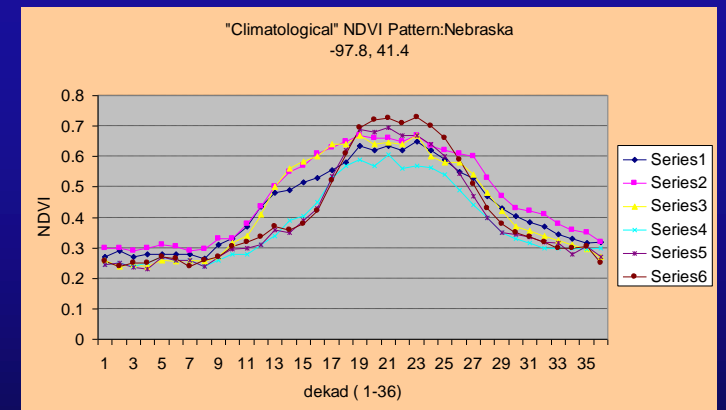
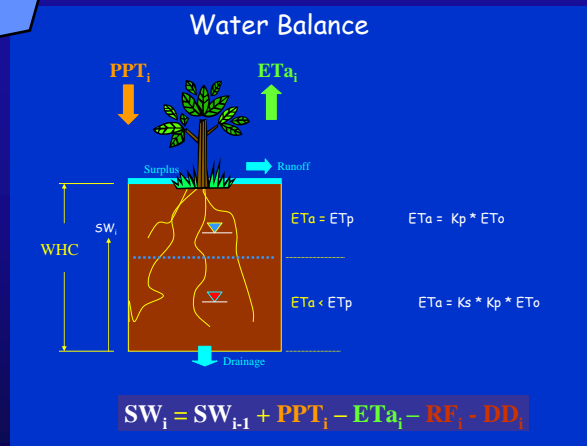
VegET

$$ETa = Ks * Kcp * ETo$$

Soil Stress Coefficient

LSP Water-Use Coefficient

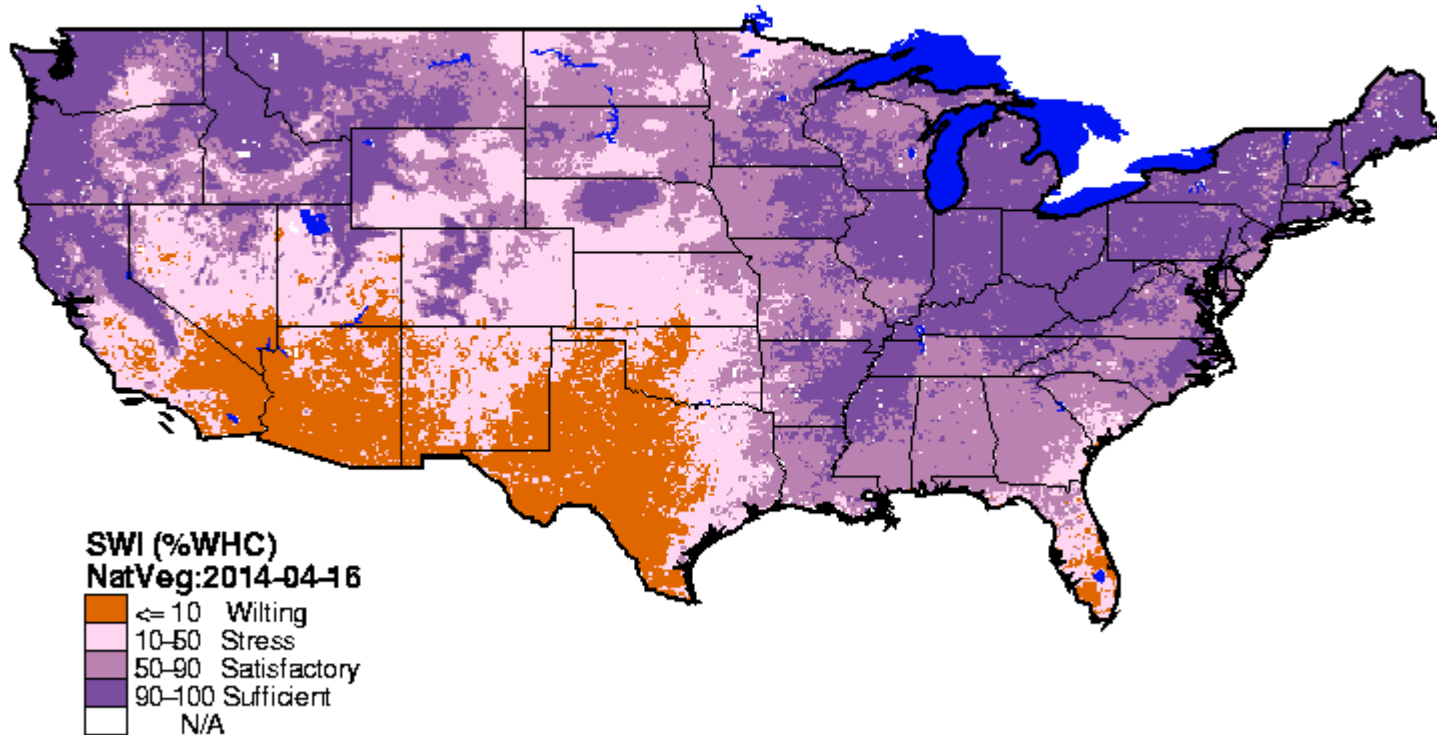
Water Balance Model



Land Surface Phenology (LSP)

Operational posting of daily Soil water index at 7:00 pm

As of Apr 16, 2014



http://earlywarning.usgs.gov/usewem/eta_water.php



Water Balance Limitations

- **Requires:**
 - rainfall data
 - characterization of vegetation water-use patterns
 - information on soils
- **Difficult to estimate:**
 - irrigation applications
 - sub-surface extraction by deep rooted plants and wetland ET
 - The impact of pest and diseases on ET

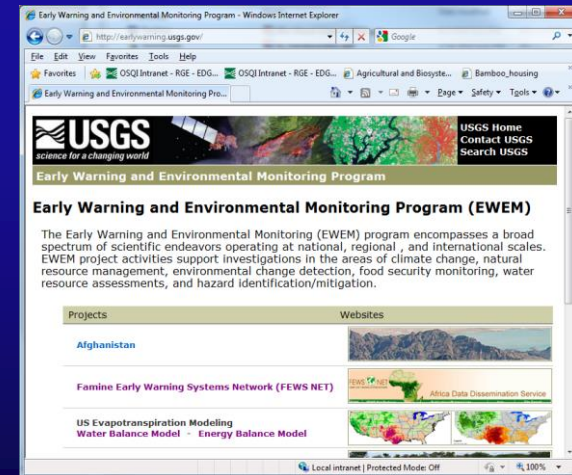


Energy Balance Approach for ET

http://earlywarning.usgs.gov/usewem/eta_energy.php

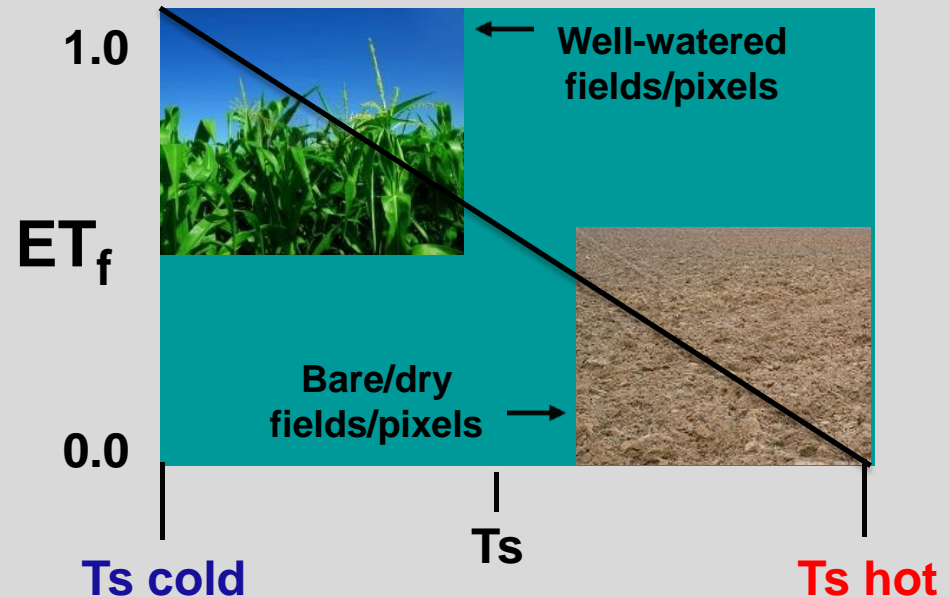
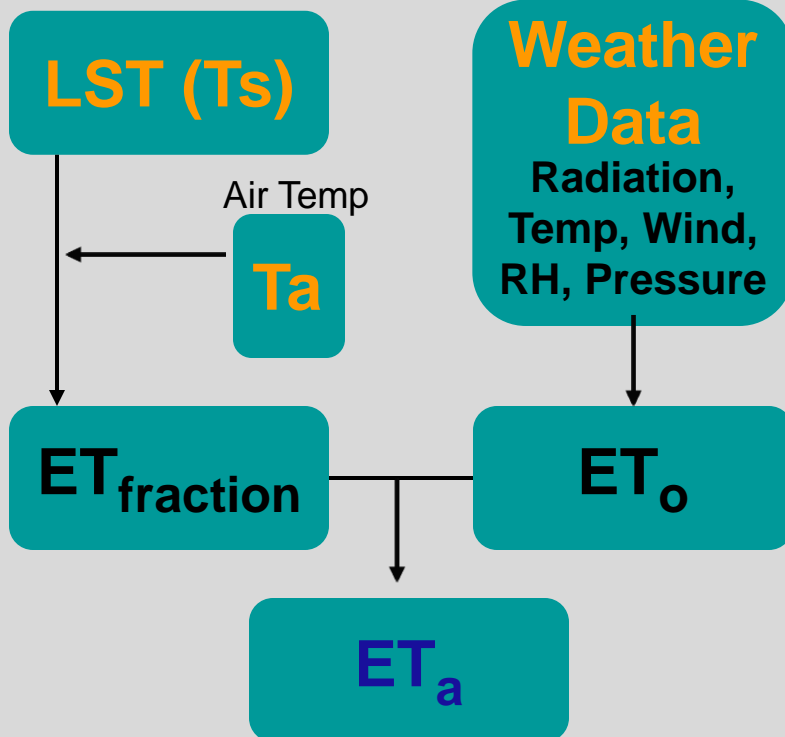
USGS **WaterSMART** and **FEWS NET** use the **SSEBop** (Operational Simplified Surface Energy Balance) approach for:

- 1) Water Use and Availability Assessment
- 2) Drought Monitoring & Early Warning



Operational Simplified Surface Energy Balance (SSEBop) Modeling Approach

Land Surface Temp



Adapted the “hot” and “cold” pixel concept from SEBAL (Bastiaanssen et al., 1998) and METRIC (Allen et al., 2007) to calculate ET fraction and combine it with ET_o .

SSEB: Senay, et al., 2007 sensors; 2011 AWM; **SSEBop**: 2013 JAWRA.



Using surface energy balance principles

ET as a Residual:

$$R_n = LE + H + G$$

$$H = \frac{\rho C_p (T_s - T_a)}{r_a}$$

$$LE = R_n - H$$

$G \approx 0$ for daily estimate

SSEBop: Pre-defined dT

Varies in space and season
but constant from year-to-year
under clear-sky conditions

RS-ET possible under “clear sky”
conditions only.

ET Direct, SSEBop:

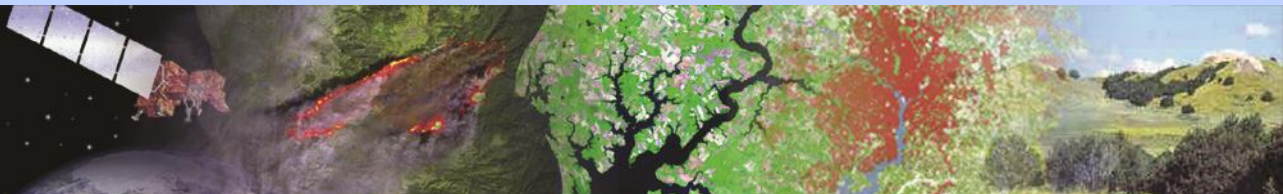
$$\lambda LE = ET = ET_f * ET_o$$

$$ET = \frac{T_h - T_s}{dT} * ET_o$$



$$dT = \frac{R_n r_a}{\rho C_p}$$

$$ET = \frac{\rho C_p (T_h - T_s)}{R_n r_a} * ET_o$$

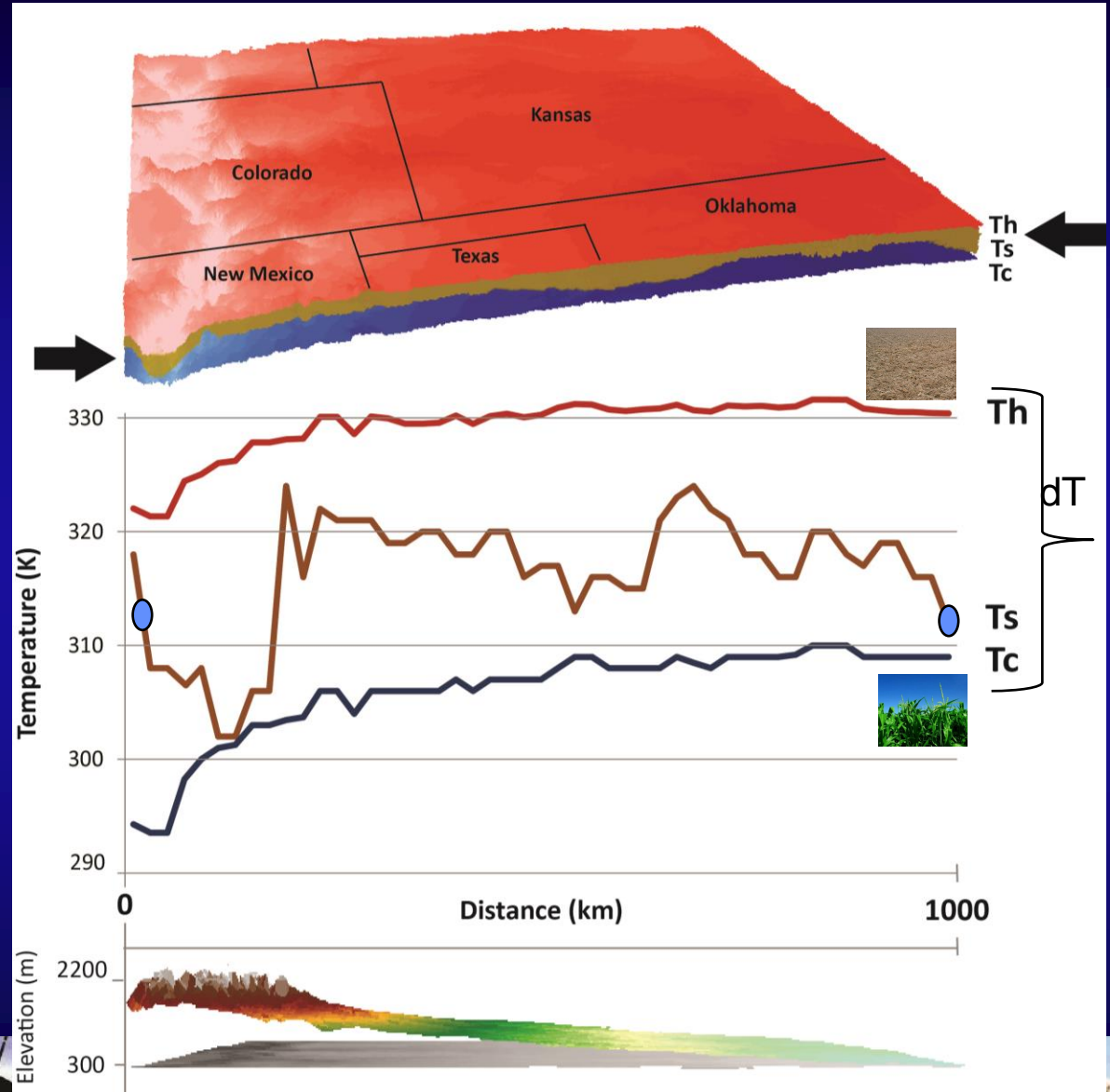


Pre-defined Boundary Conditions are KEY!



Jul 4, 2012

Transect:
Ts = MODIS LST
Tc = Cold boundary (Ta_max)
Th = Tc + dT



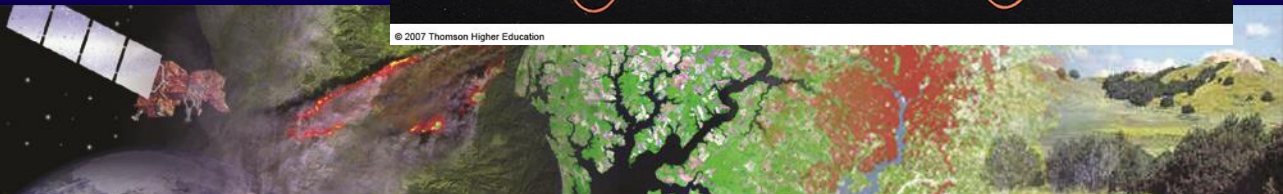
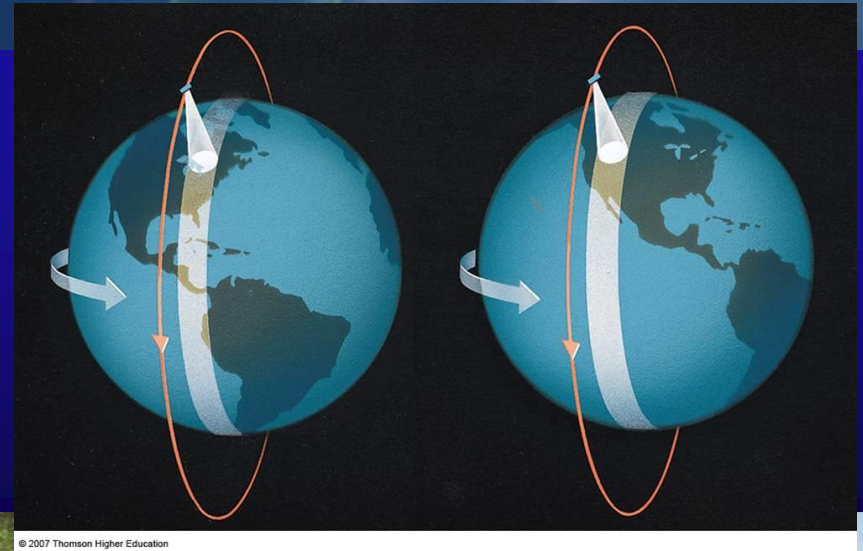
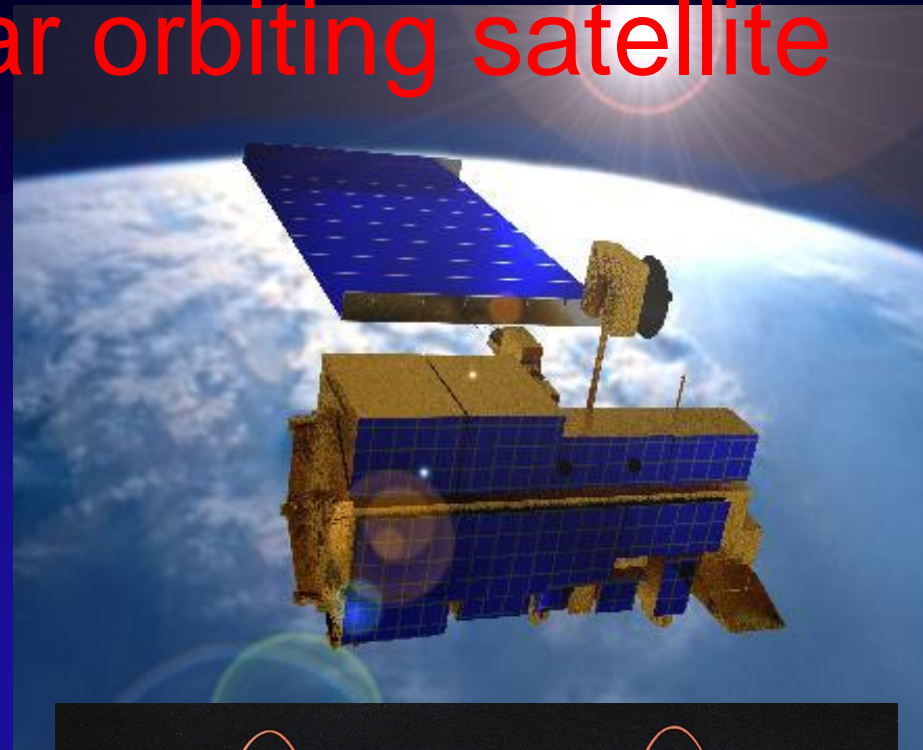
Source of LST and reference ETo

- Land Surface Temperature (LST) from thermal imagery
 - Current implementation with SSEBop
 - Landsat (~100m)
 - MODIS (1km)
- Air Temp: Daymet, PRISM, Worldclim
- ETo: model assimilated global weather datasets such as GDAS and NLDAS or station-based P-M ETo fields.

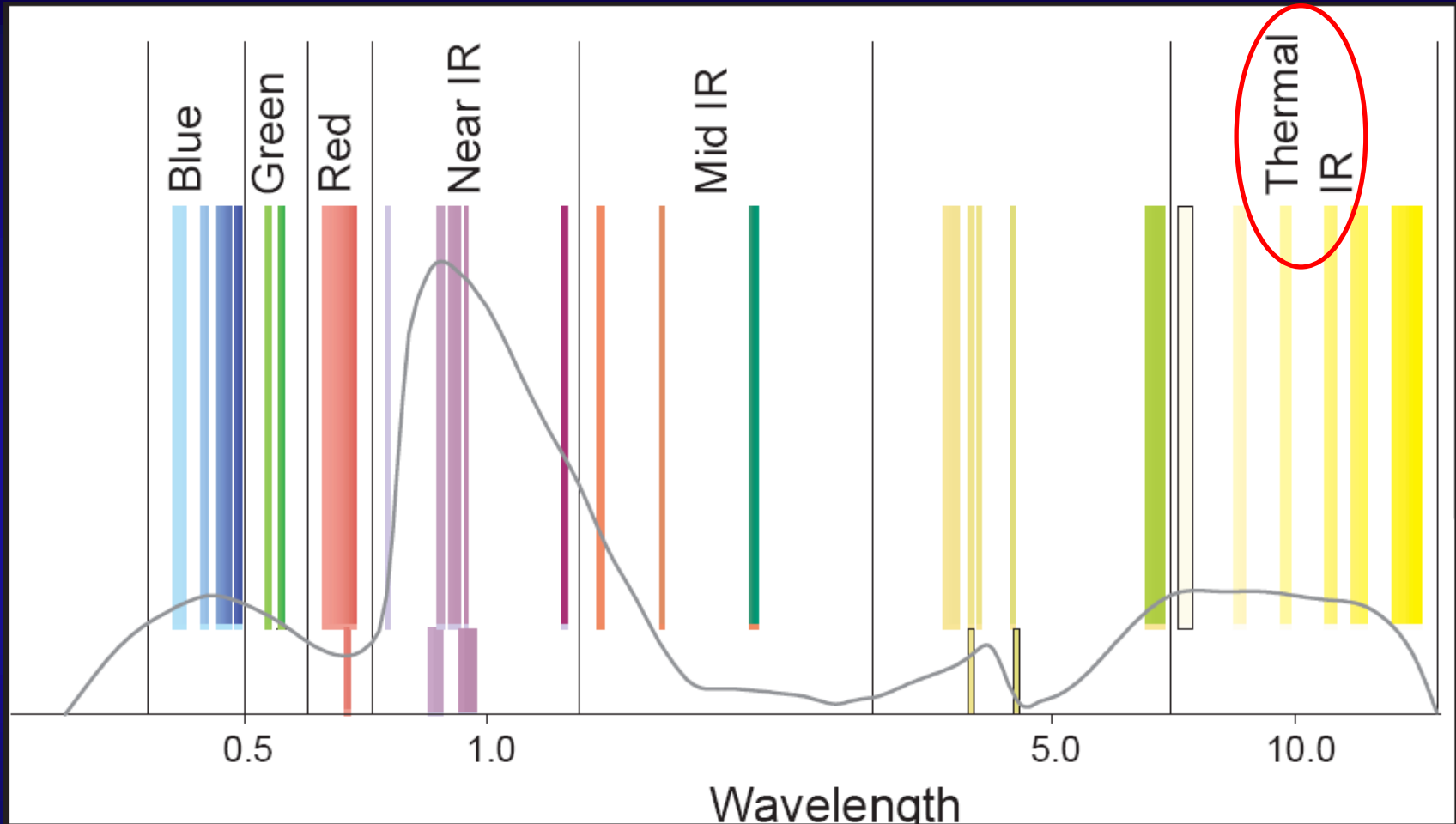


Images from a polar orbiting satellite

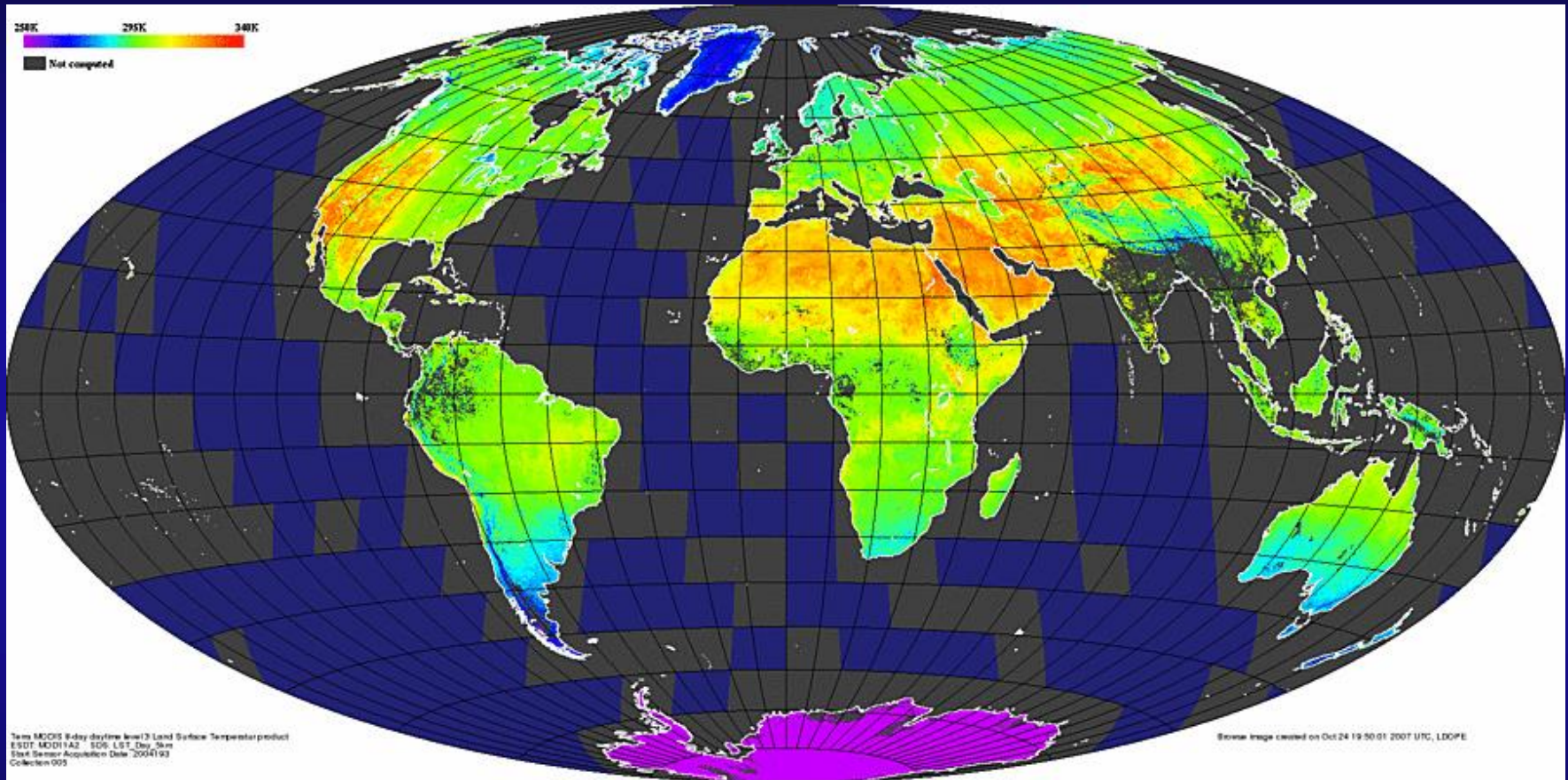
Satellite: Terra (EOS AM-1)
Sensors: MODIS, and 4 others
Altitude: 725 km
Repeat: daily at 10:30 am
Period: 98.8 minutes



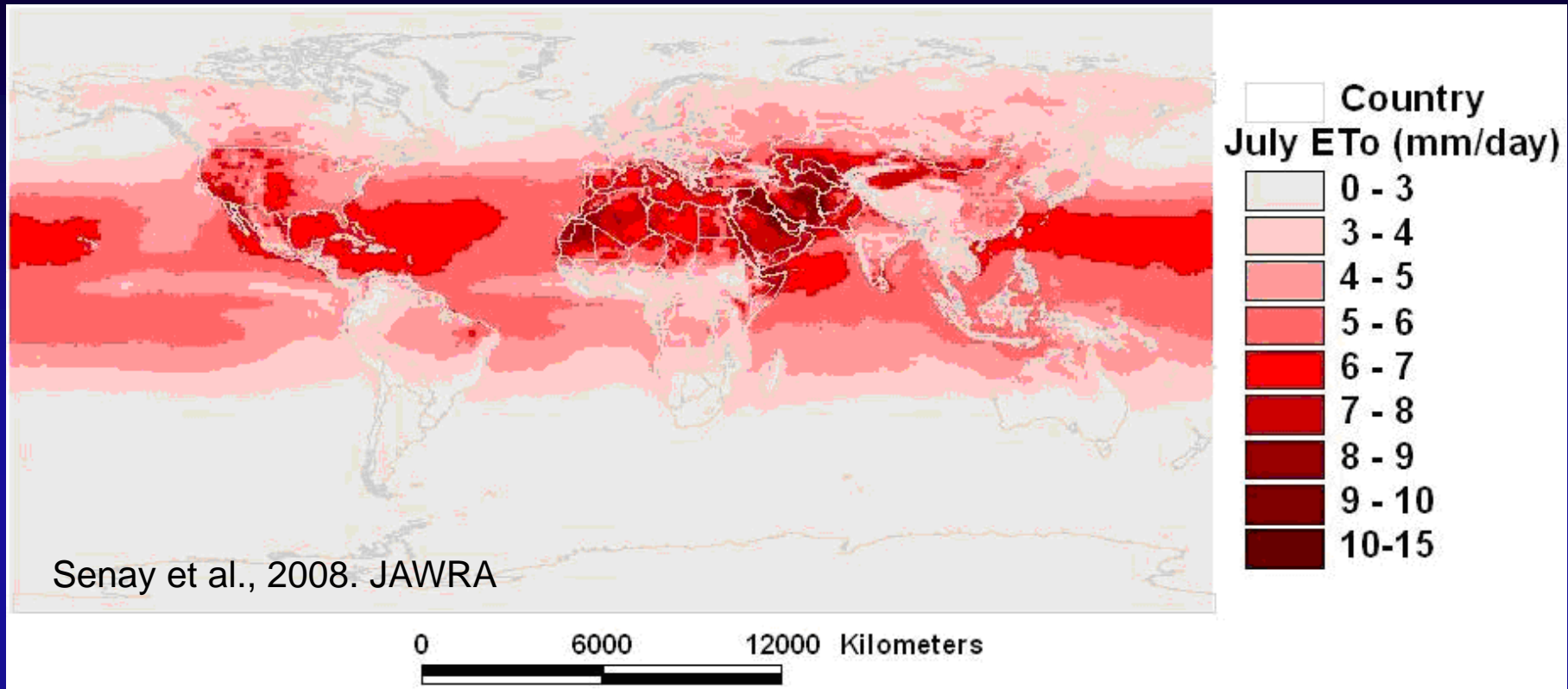
MODIS Spectral Bands (36)



MODIS 8-day Land Surface Temperature (1-km spatial resolution)



Daily Global GDAS ETo for July 2004



$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

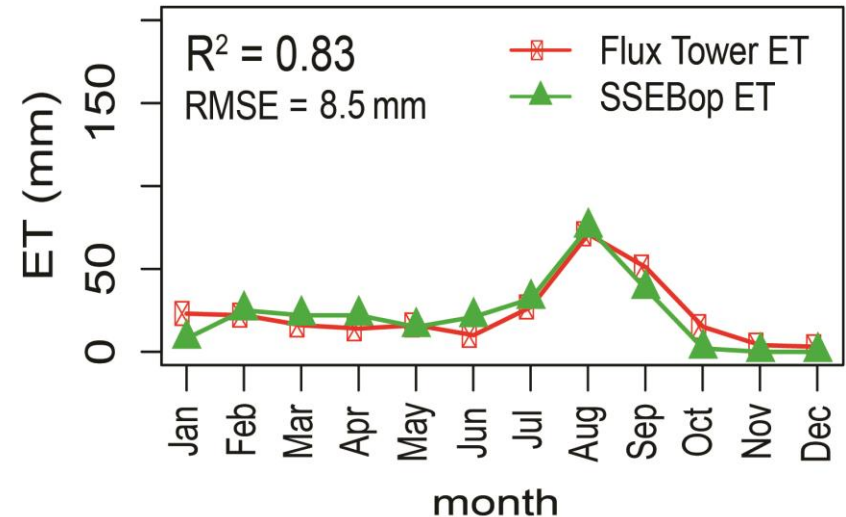
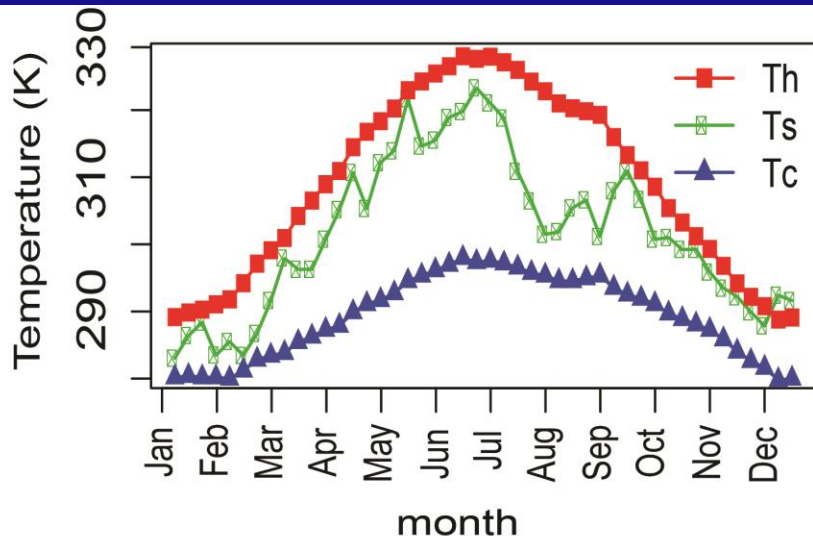
6-hr weather forecast data from NOAA:
Radiation, temp, wind, RH and pressure
to solve the standardized P-M Equation

<http://earlywarning.usgs.gov/Global/dwnglobalpet.php>



SSEBop Illustrative Validation with EC Flux Towers

EC Flux Tower: Audubon, AZ, 2005



Senay et al., 2013. JAWRA

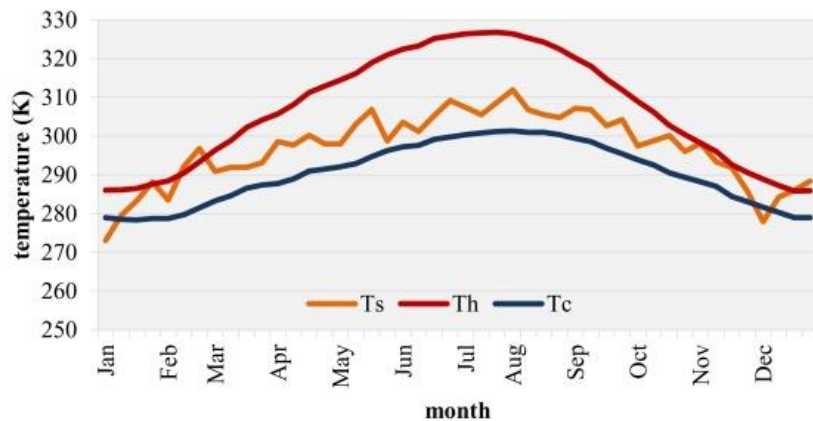


Validation in Oklahoma, 2005

AmeriFlux EC Tower

(C) ARM_SGP_Burn Station, OK

8-day Ts, Th, and Tc



Monthly Flux Tower and SSEB model ET



Inter-comparison of 4 ET Estimates

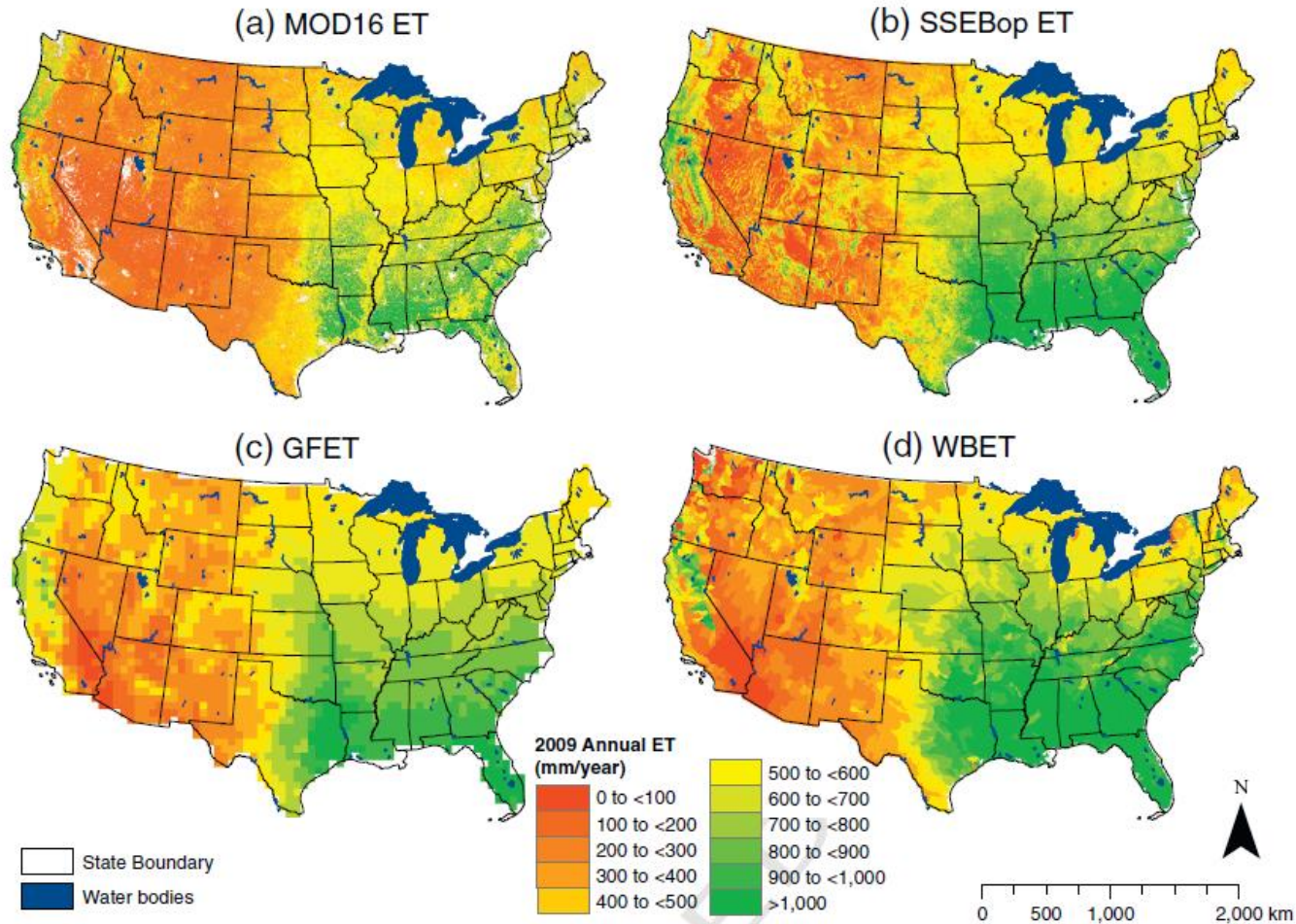
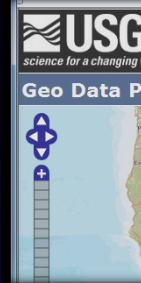


Fig. 8. Spatially explicit 2009 annual evapotranspiration datasets for the CONUS (a) MOD16 ET 1 km, (b) SSEBop ET 1 km, (c) gridded FLUXNET ET (GFET) 50 km and (d) HUC8 water balance ET (WBET).

Velpuri et al., 2013. RSE



Geo Data Portal Information

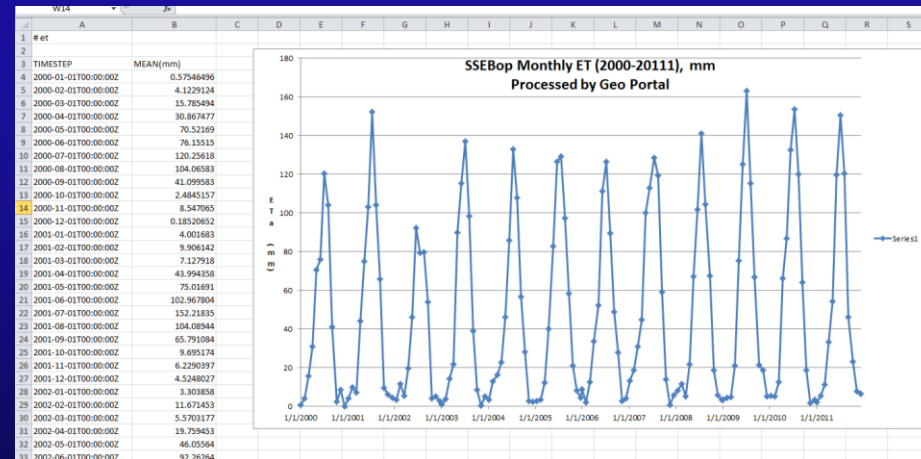
Downscaled Climate Geo Data Portal

Returning Users: Please refresh this page while holding shift to refresh any cached versions. The Geo Data Portal was released on 5/17/2013 including a critical bug fix. If selecting a shapefile does not work, please contact gdp@usgs.gov.

ET Data on USGS Geo Portal

<http://cida.usgs.gov/climate/gdp/>
(Center for Integrated Data Analytics)

Monthly and yearly grids:
2000-2013



Global and Regional Operational Products

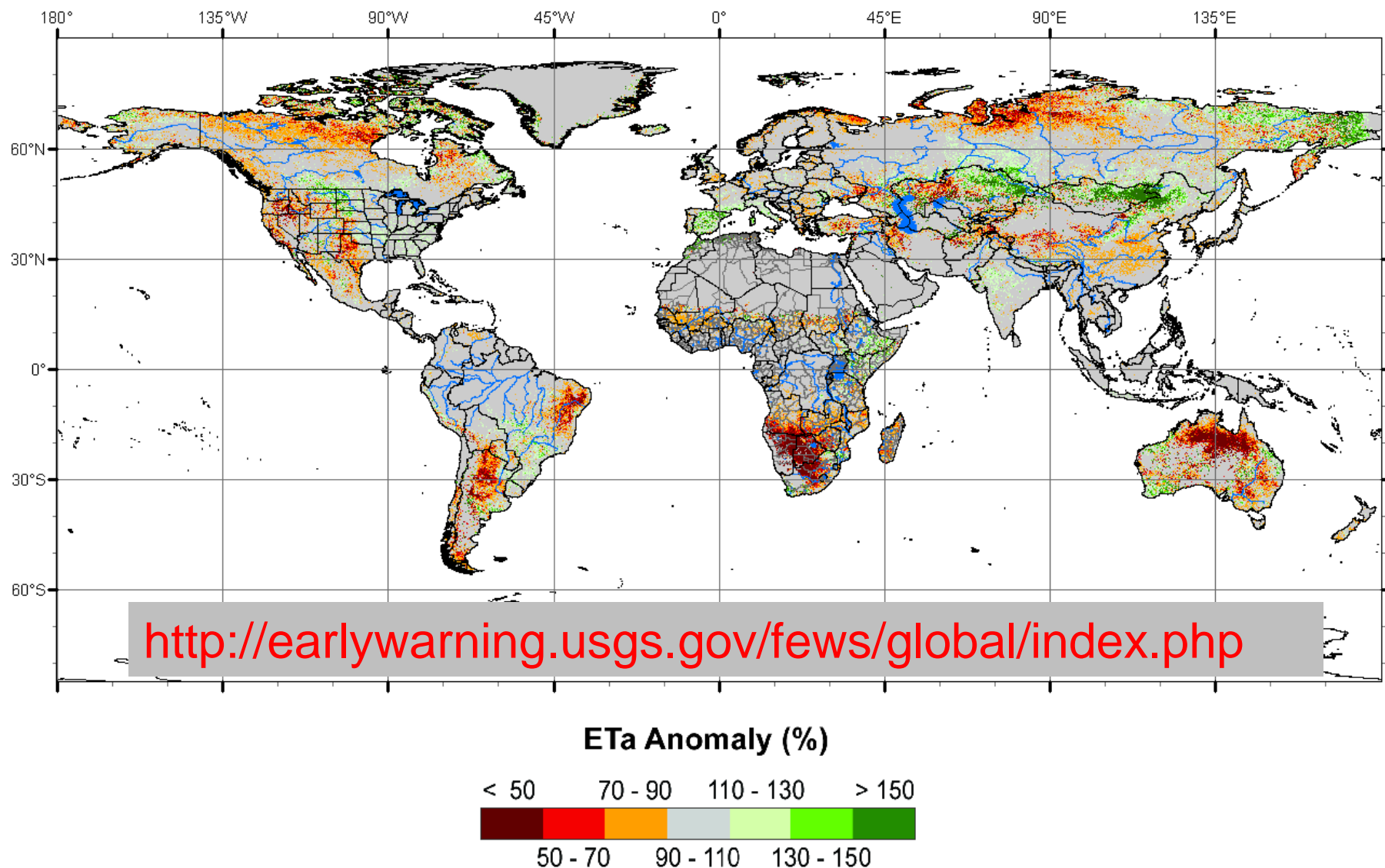
MODIS: for Global and Regional

Landsat: for local/sub-basin scale applications



Cumulative ETa Anomaly: Mar Dekad 1 - Oct Dekad 3, 2013

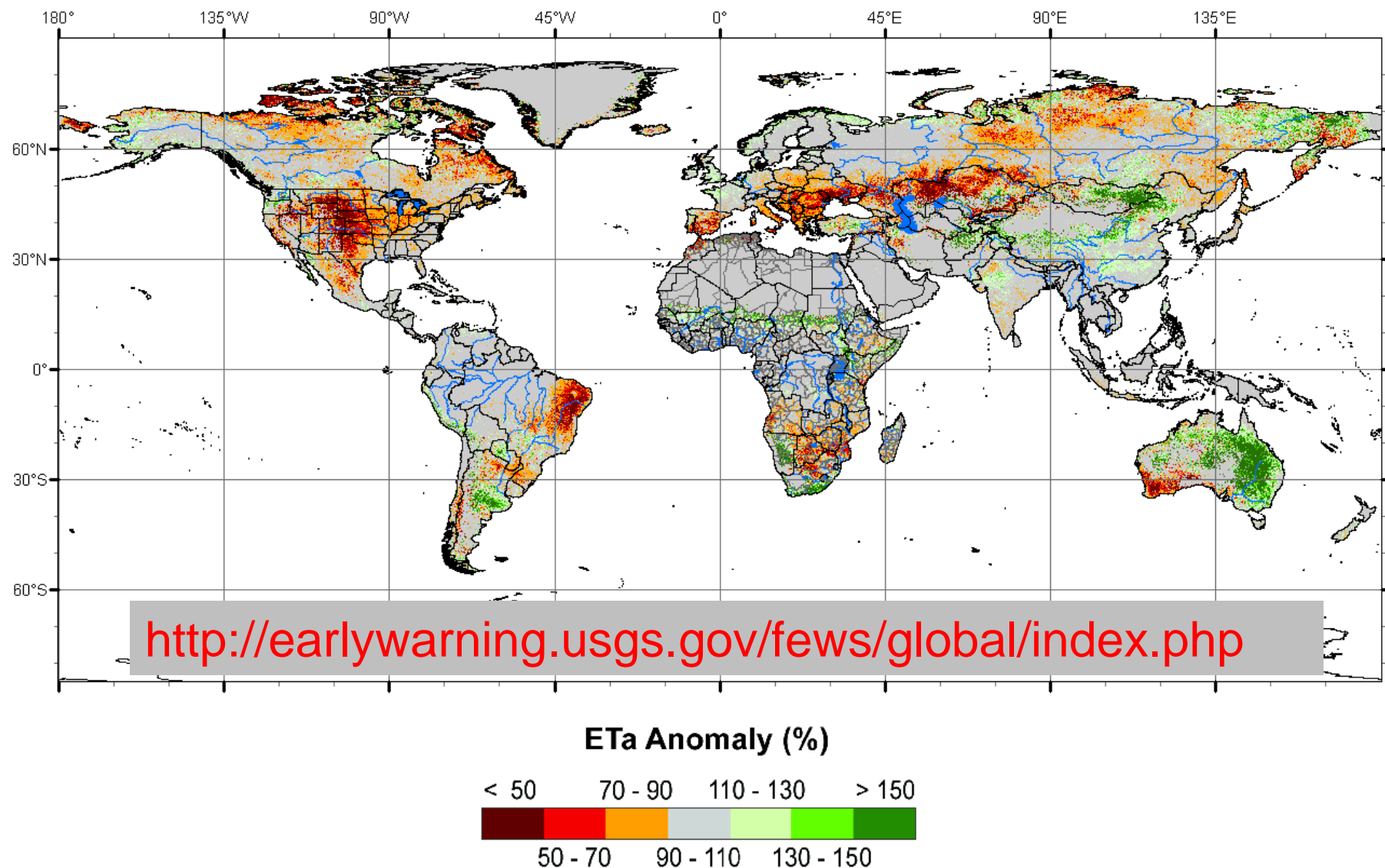
Percent of Average (2003-2013)



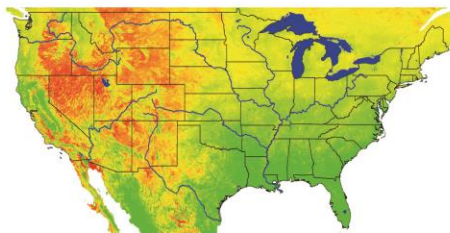
<http://earlywarning.usgs.gov/fews/global/index.php>

Cumulative ETa Anomaly: Mar Dekad 1 - Oct Dekad 3, 2012

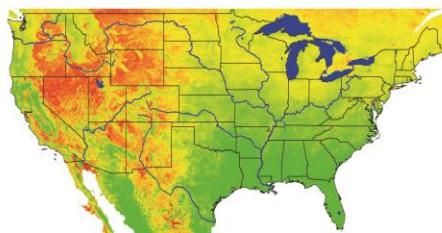
Percent of Average (2003-2013)



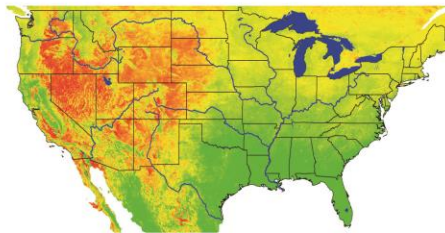
2000



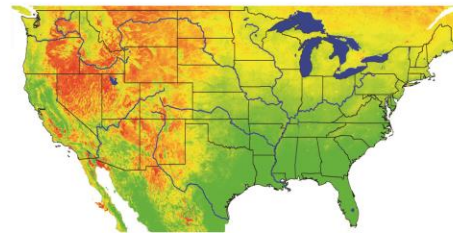
2001



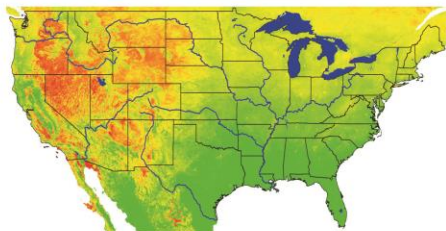
2002



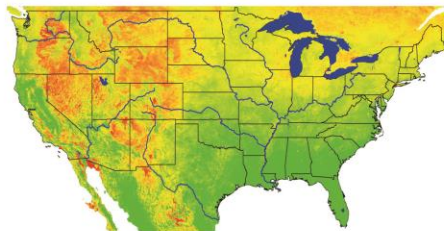
2003



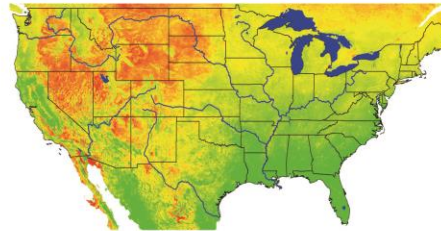
2004



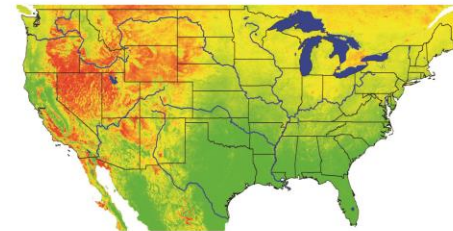
2005



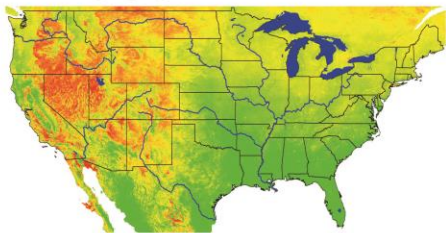
2006



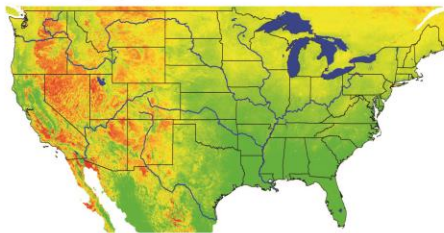
2007



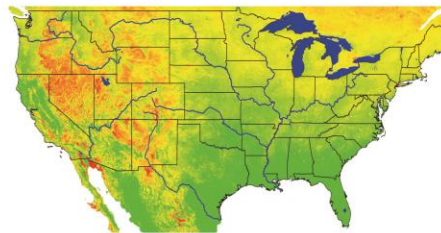
2008



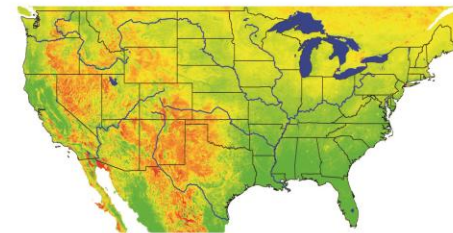
2009



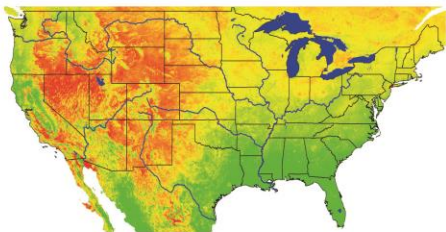
2010



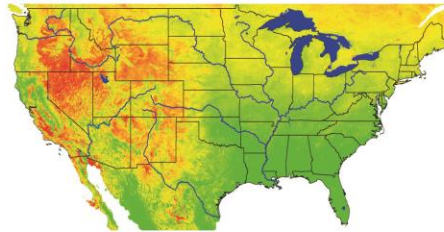
2011



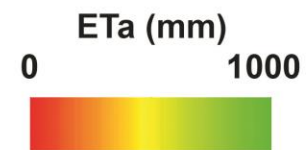
2012



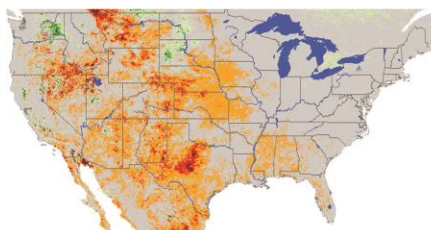
2013



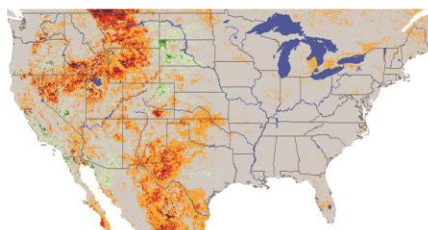
Annual ET



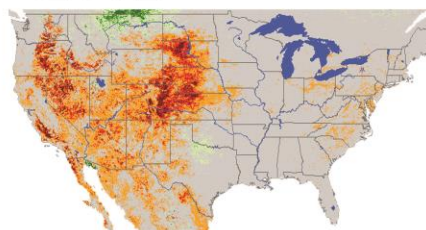
2000



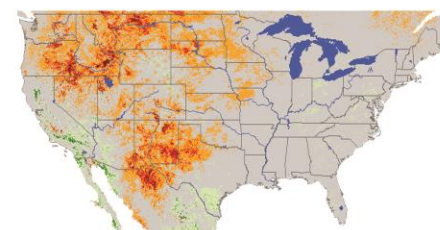
2001



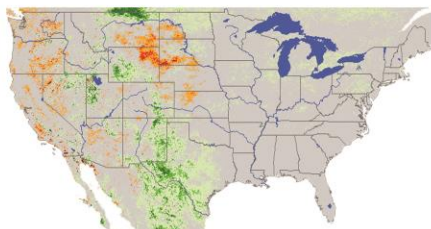
2002



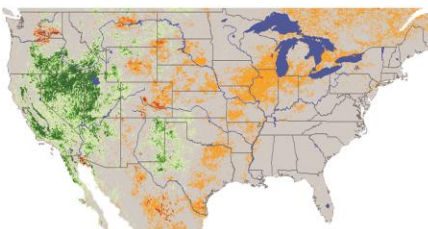
2003



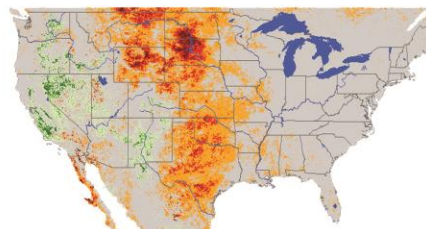
2004



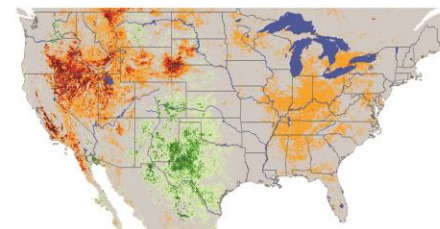
2005



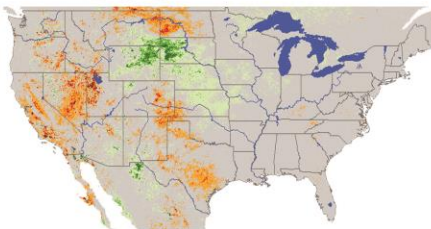
2006



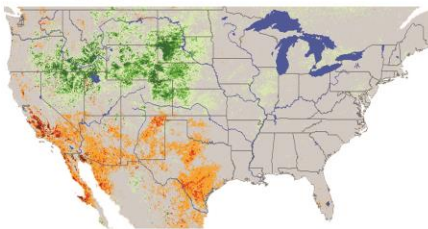
2007



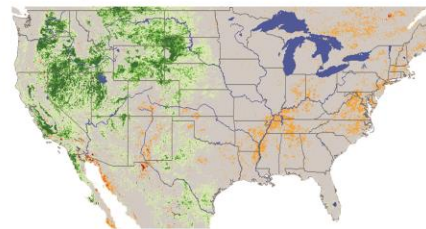
2008



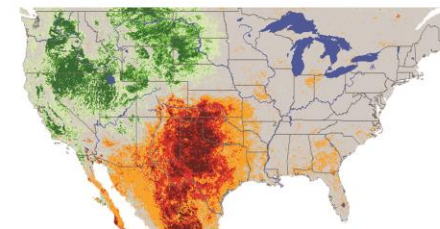
2009



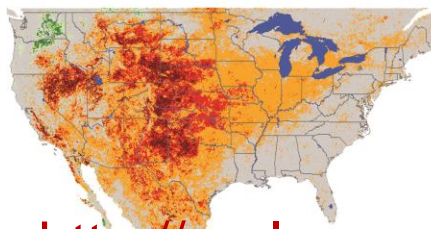
2010



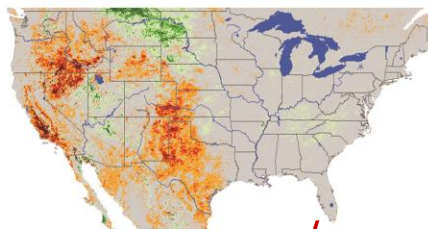
2011



2012

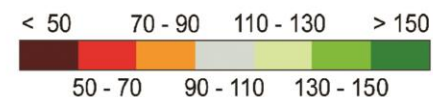


2013



Annual ET Anomaly

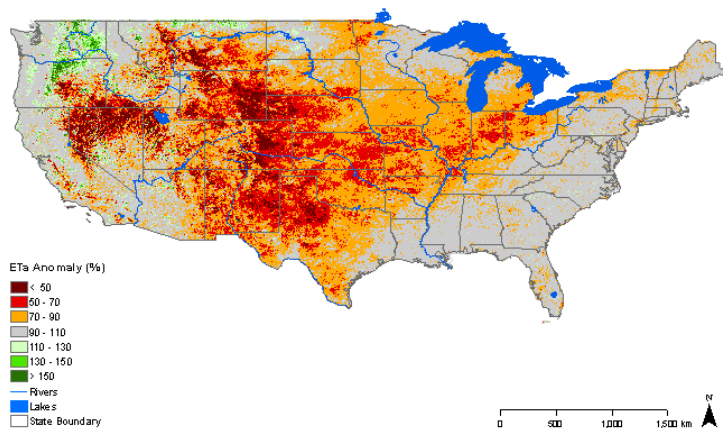
ETa Anomaly (%)



<http://earlywarning.usgs.gov/usewem/eta8dayhist.php>

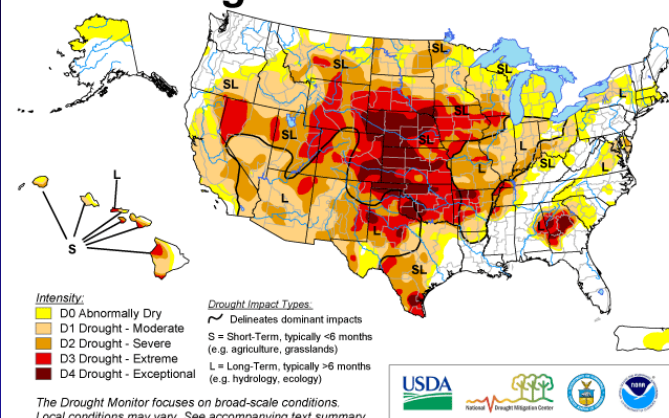
2012 Seasonal ETa Anomaly

(Apr- Oct)



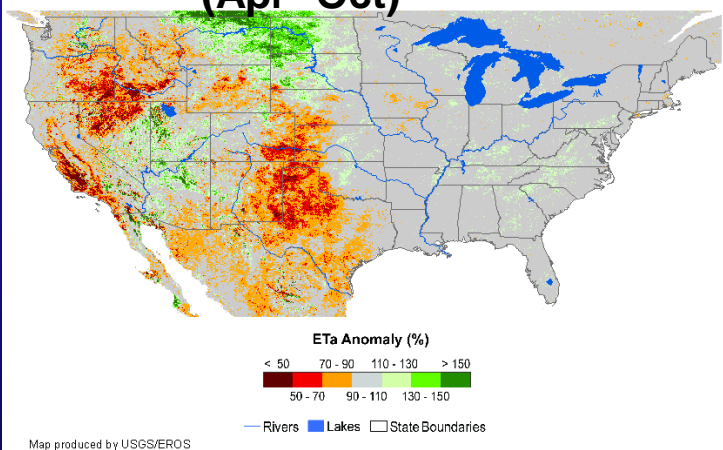
U.S. Drought Monitor

September 18, 2012
Valid 7 a.m. EDT



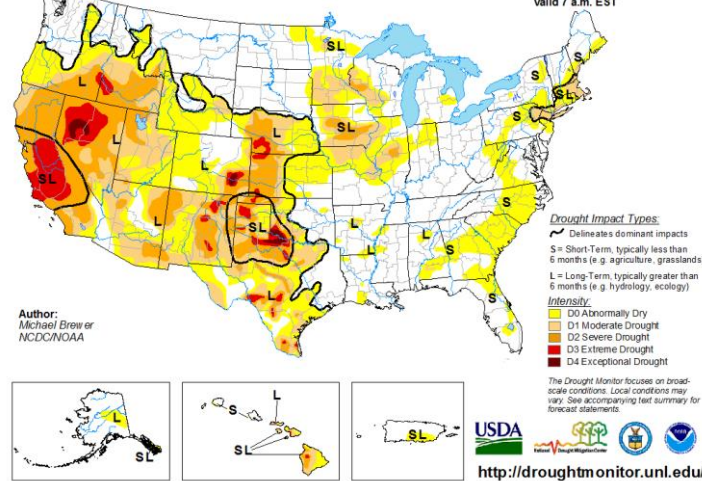
2013 Seasonal ETa Anomaly

(Apr- Oct)



U.S. Drought Monitor

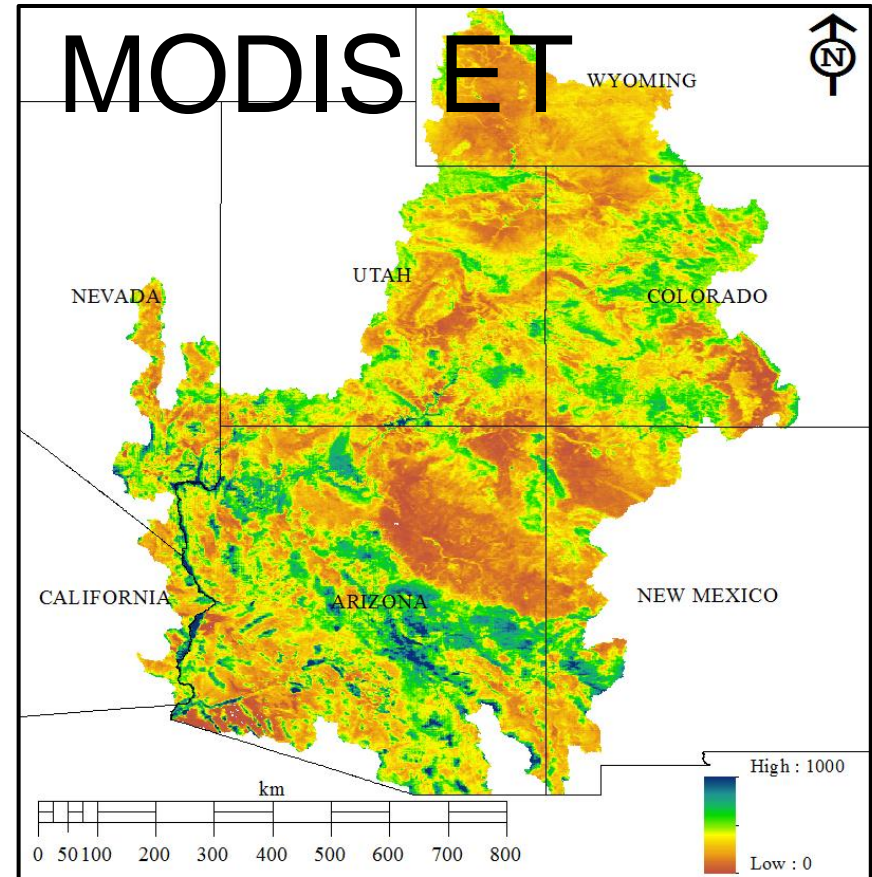
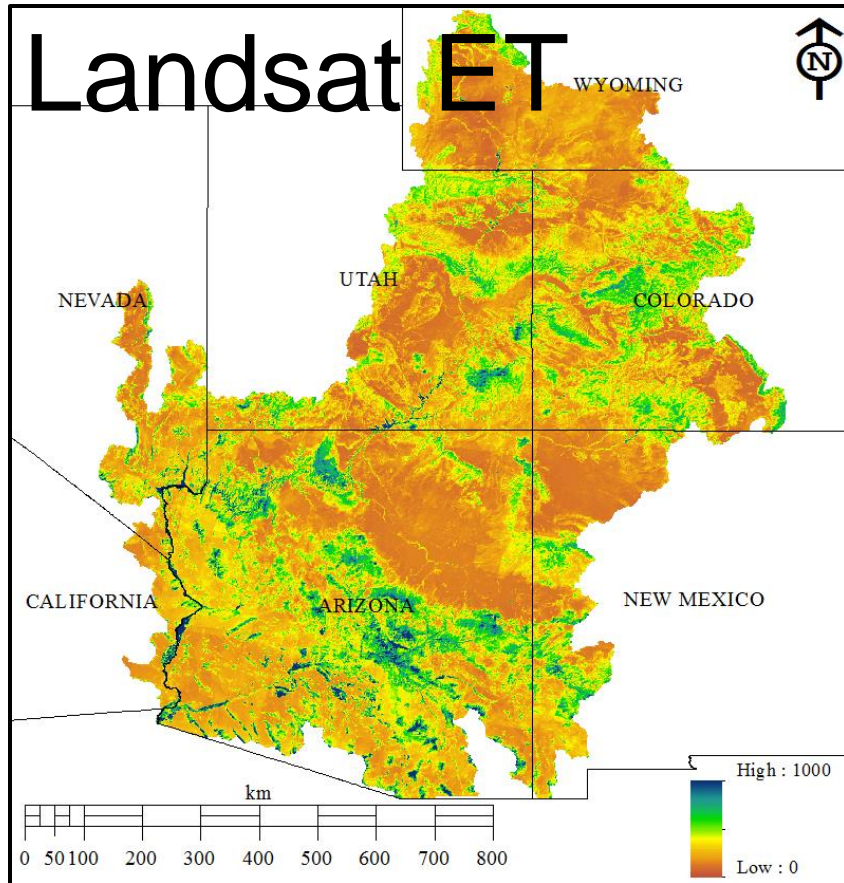
December 3, 2013
(Released Thursday, Dec. 5, 2013)
Valid 7 a.m. EST



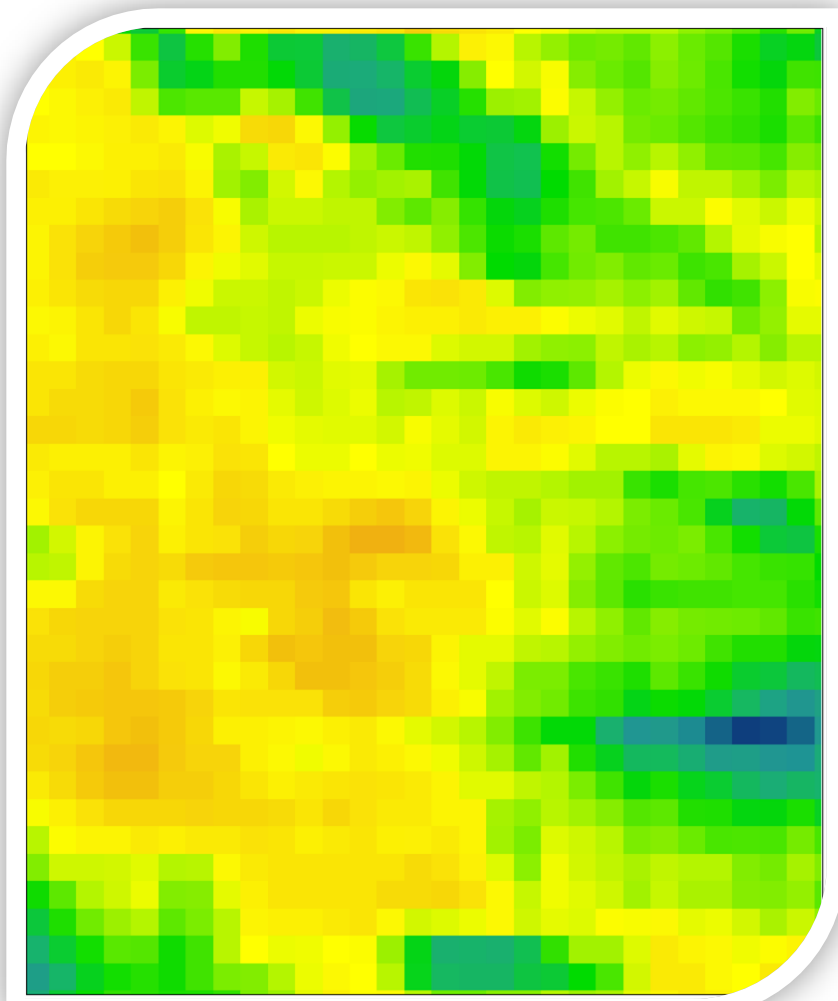
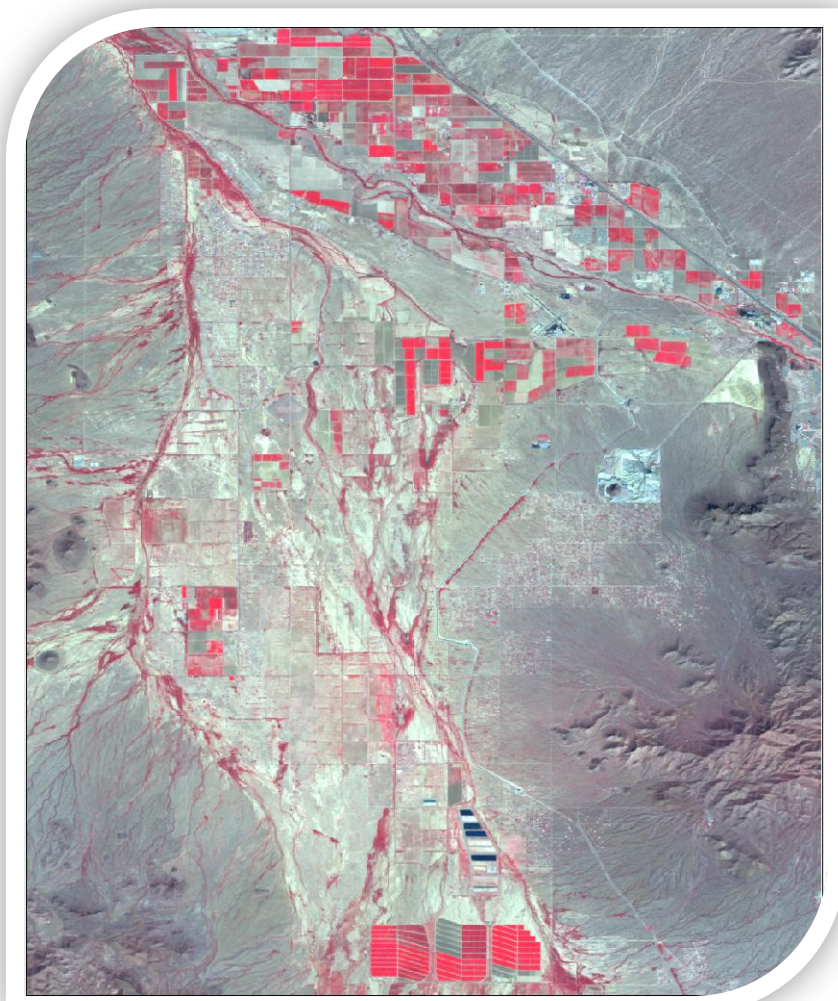
Landsat Scale ET: Water use at a field scale including golf courses...



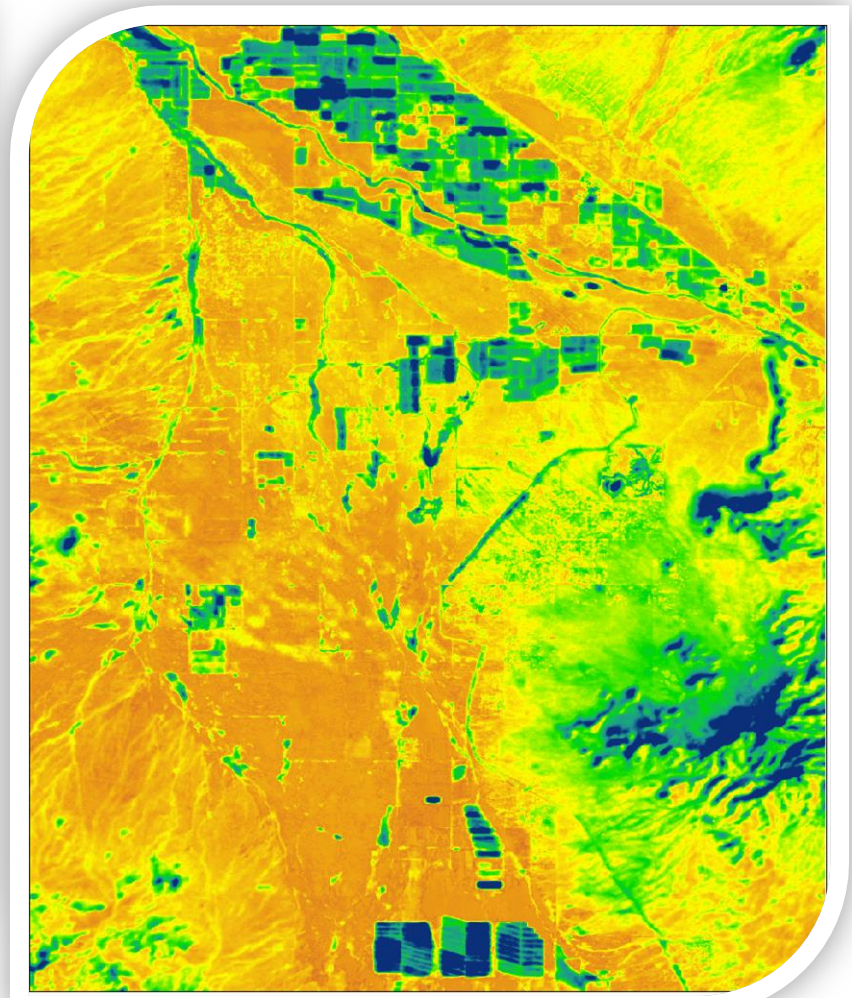
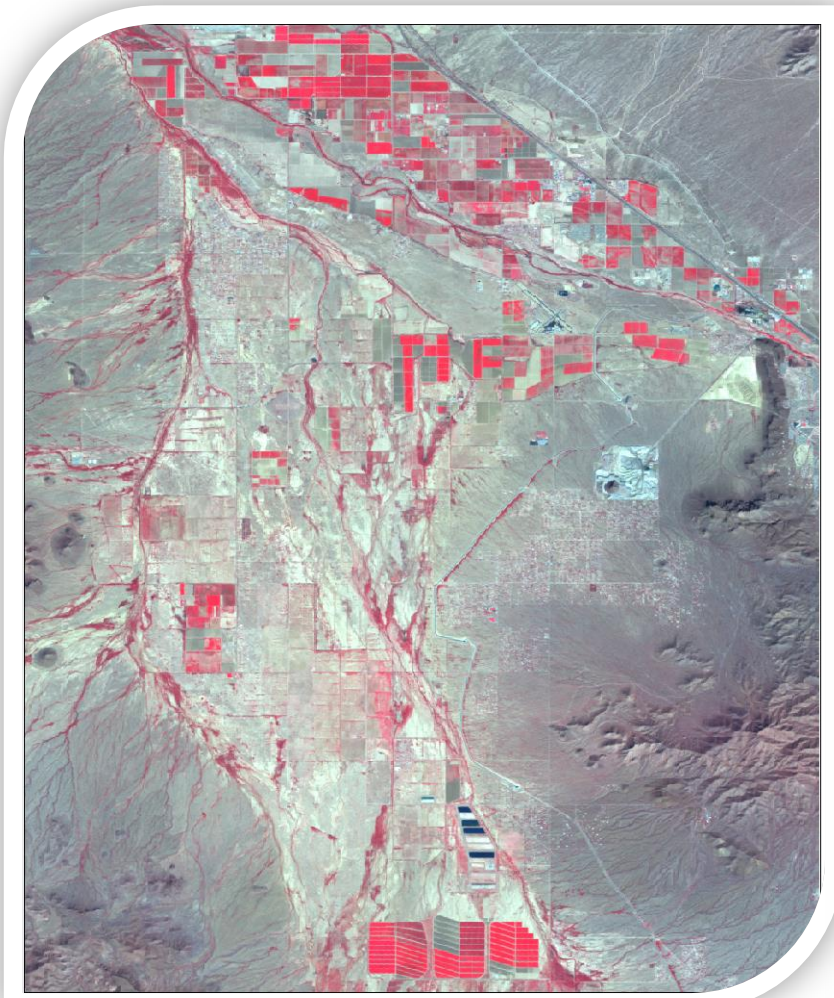
Colorado River Basin Annual ET 2010 (mm): 1st ever for CRB, seamless Landsat ET!



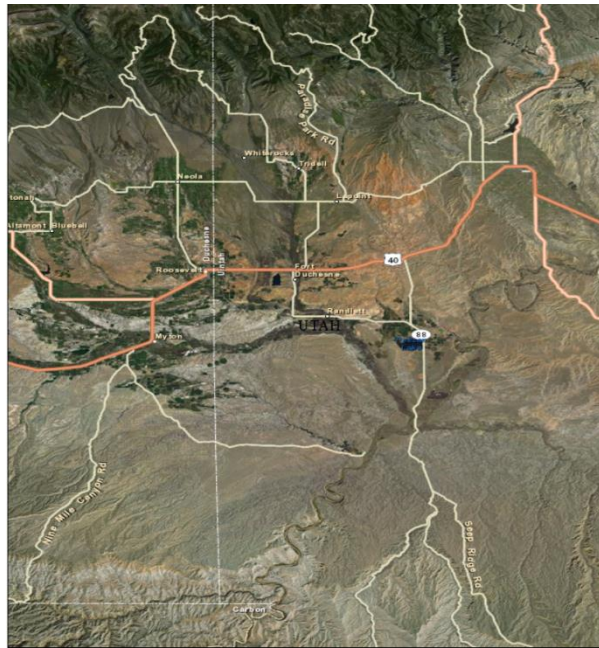
Zoom in of MODIS Annual ET (SSEBop)



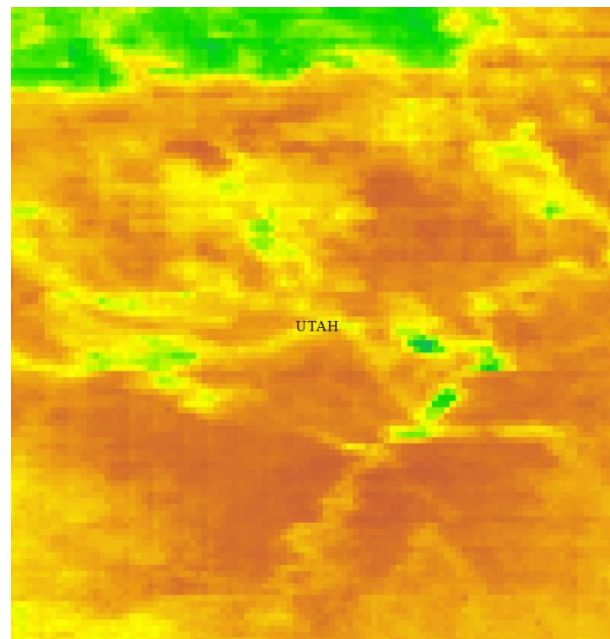
Zoom in of Landsat Annual ET (SSEBop)



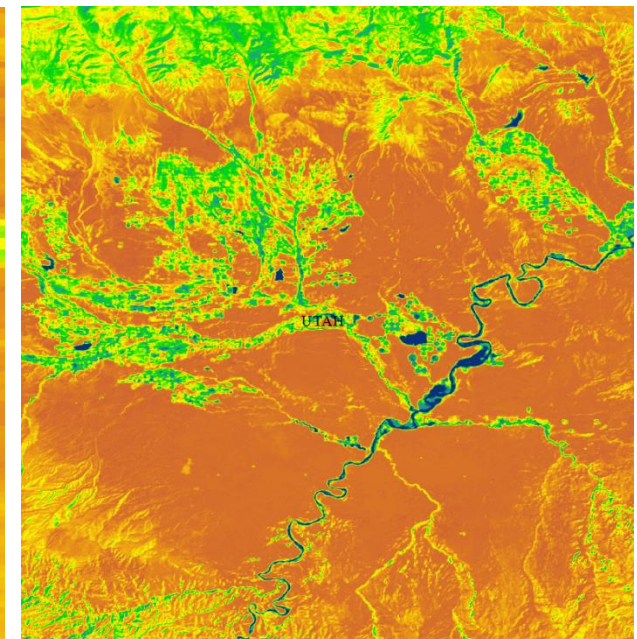
Close up View of MODIS and Landsat Annual ET With Respect to Base Map



Base Map



MODIS ET

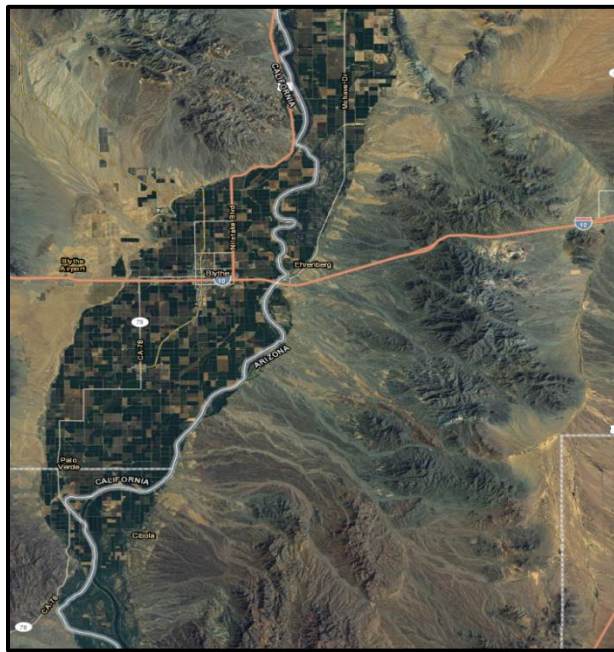


Landsat ET

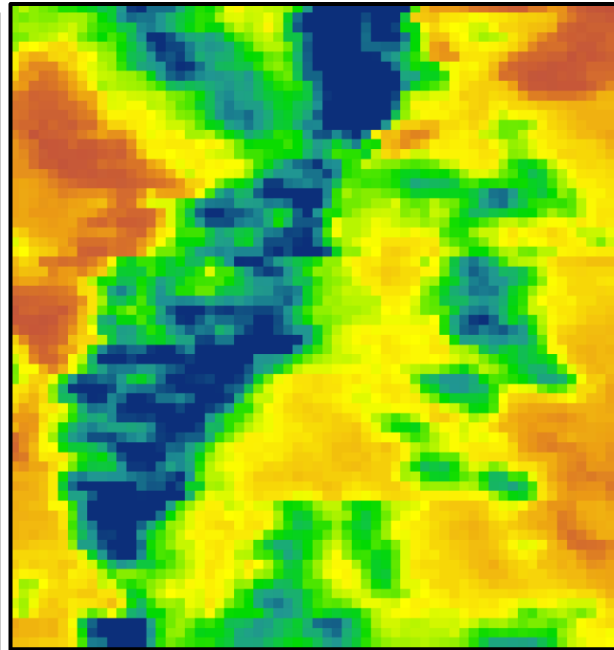
0 1000 mm



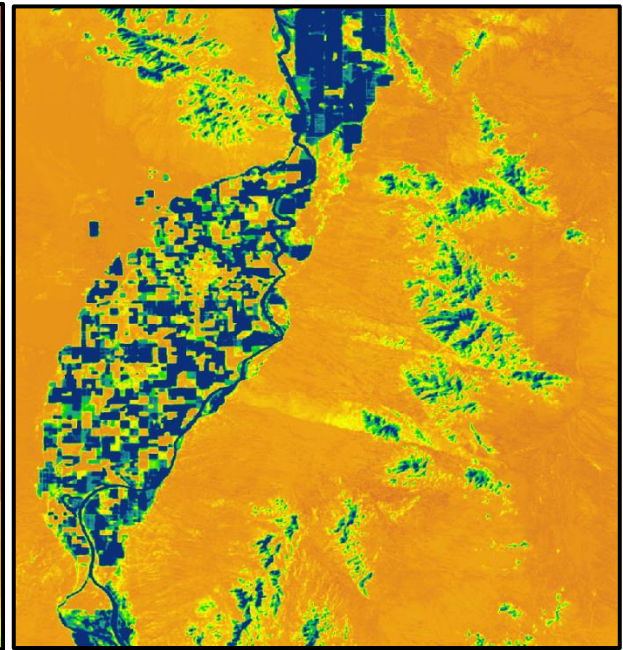
Close up View of MODIS and Landsat Annual ET With Respect to Base Map



Base Map



MODIS ET

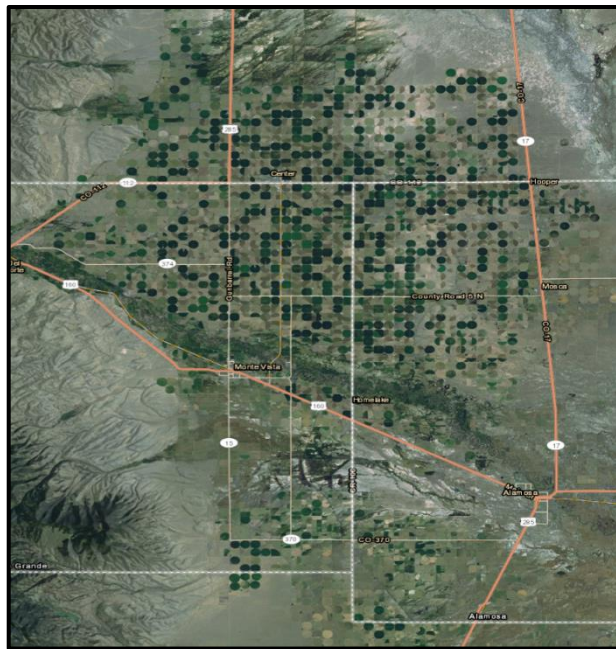


Landsat ET

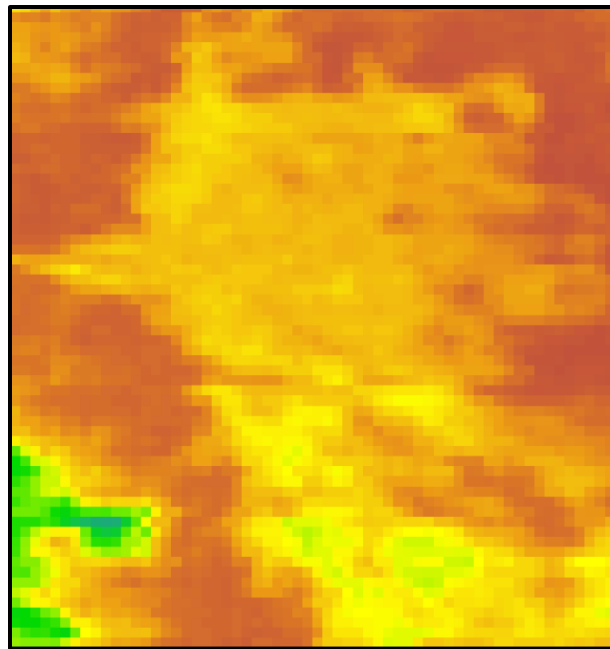
0 1000 mm



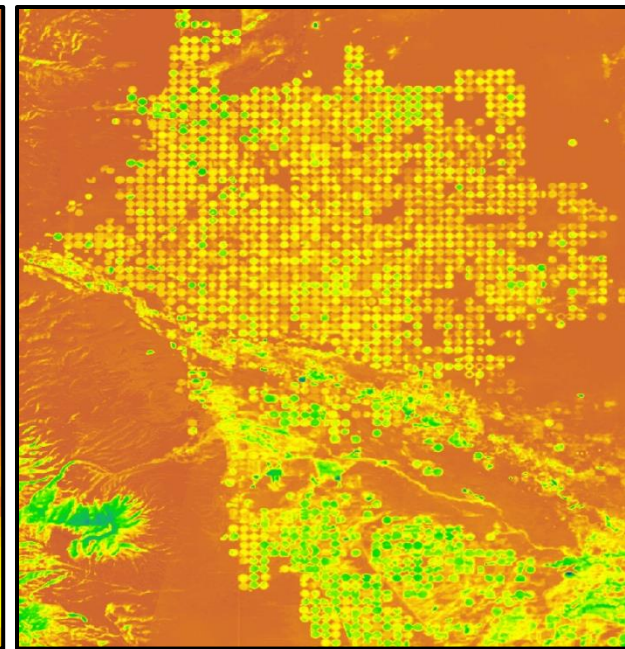
Close up View of MODIS and Landsat Annual ET With Respect to Base Map



Base Map



MODIS FT

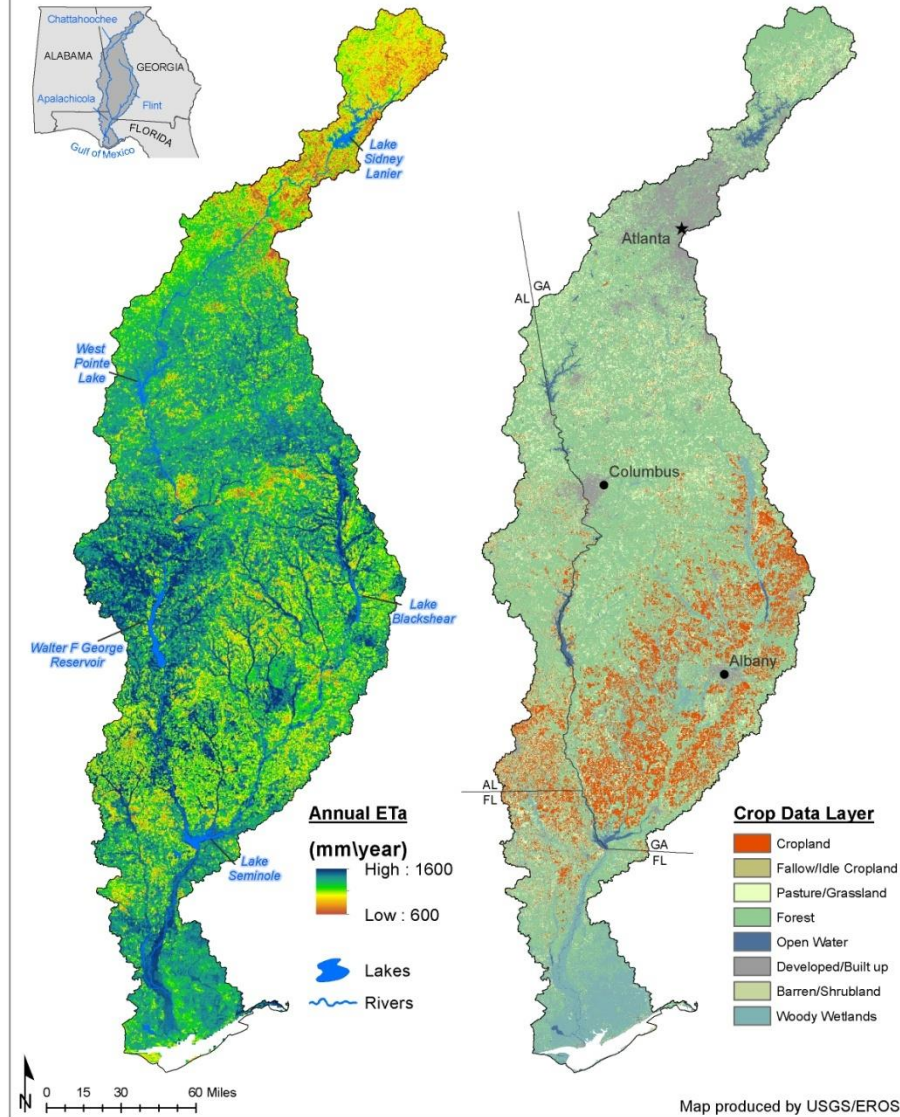


Landsat ET

0 1000 mm



ACF 2010 Annual ETa and Crop Data Layer



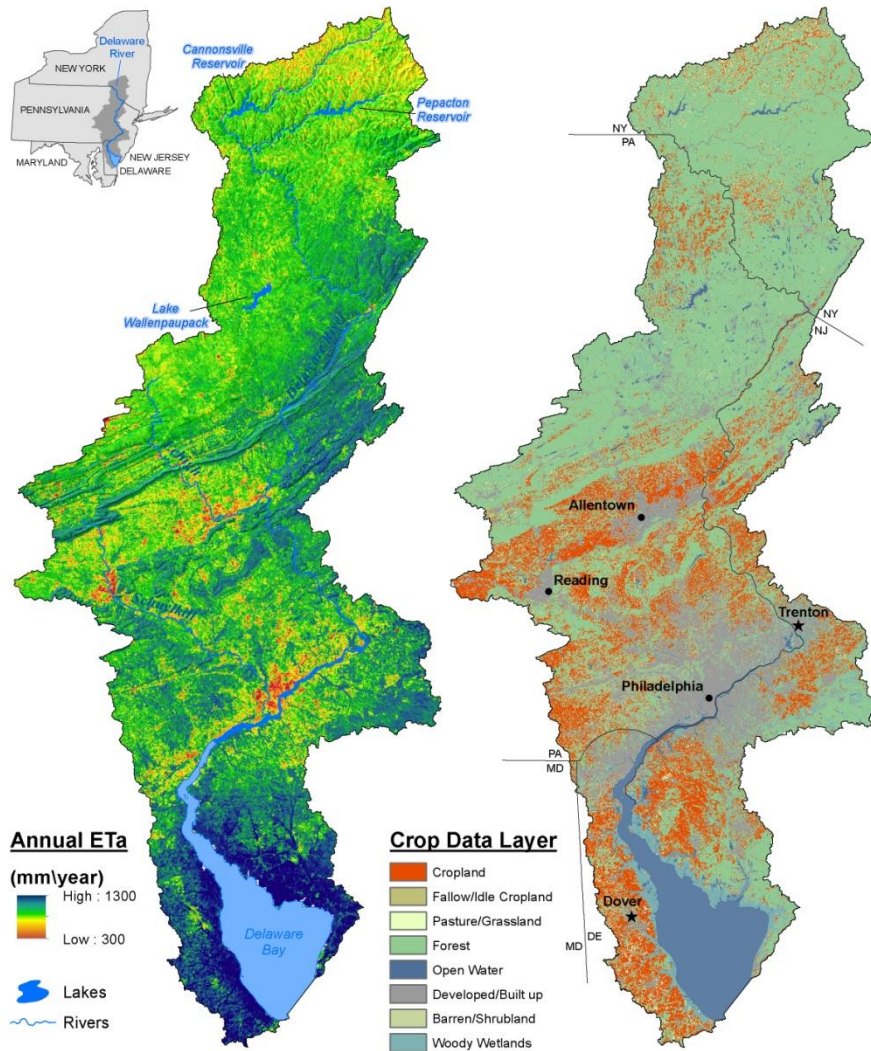
Apalachicola- Chattahoochee- Flint River Basin

Crops
have lower
annual ET than
Natural Vegetation
in the Southeast!

Model:
SSEBop on Landsat



DRB 2010 Annual ETa and Crop Data Layer

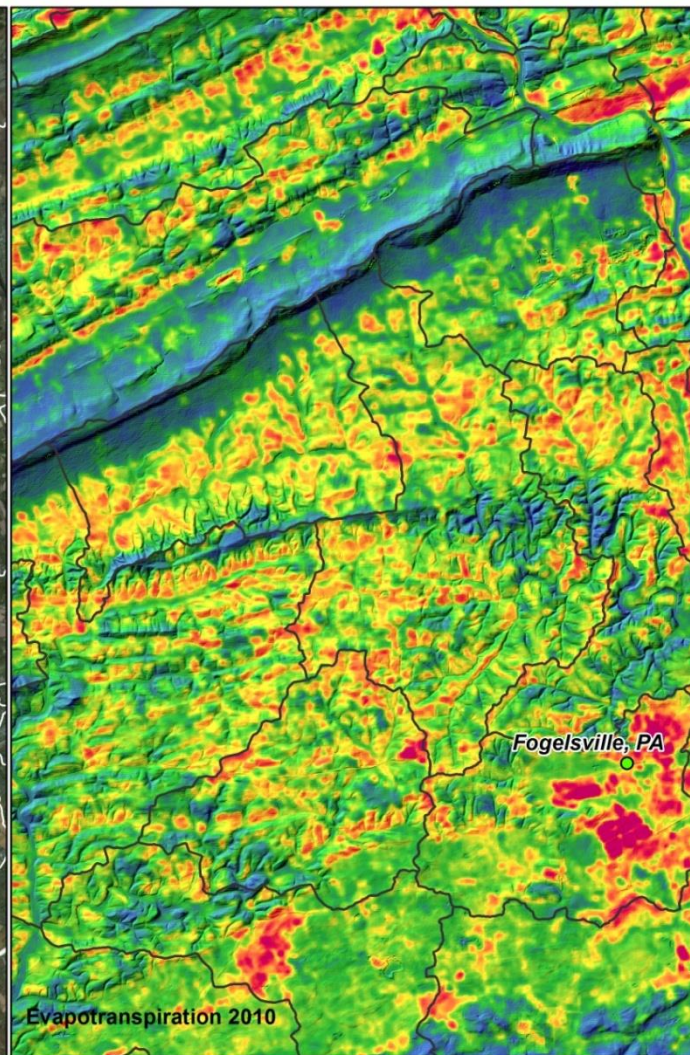


Map produced by USGS/EROS

Model:
SSEBop on Landsat



DRB Close up View



Annual ETa

(mm/year)



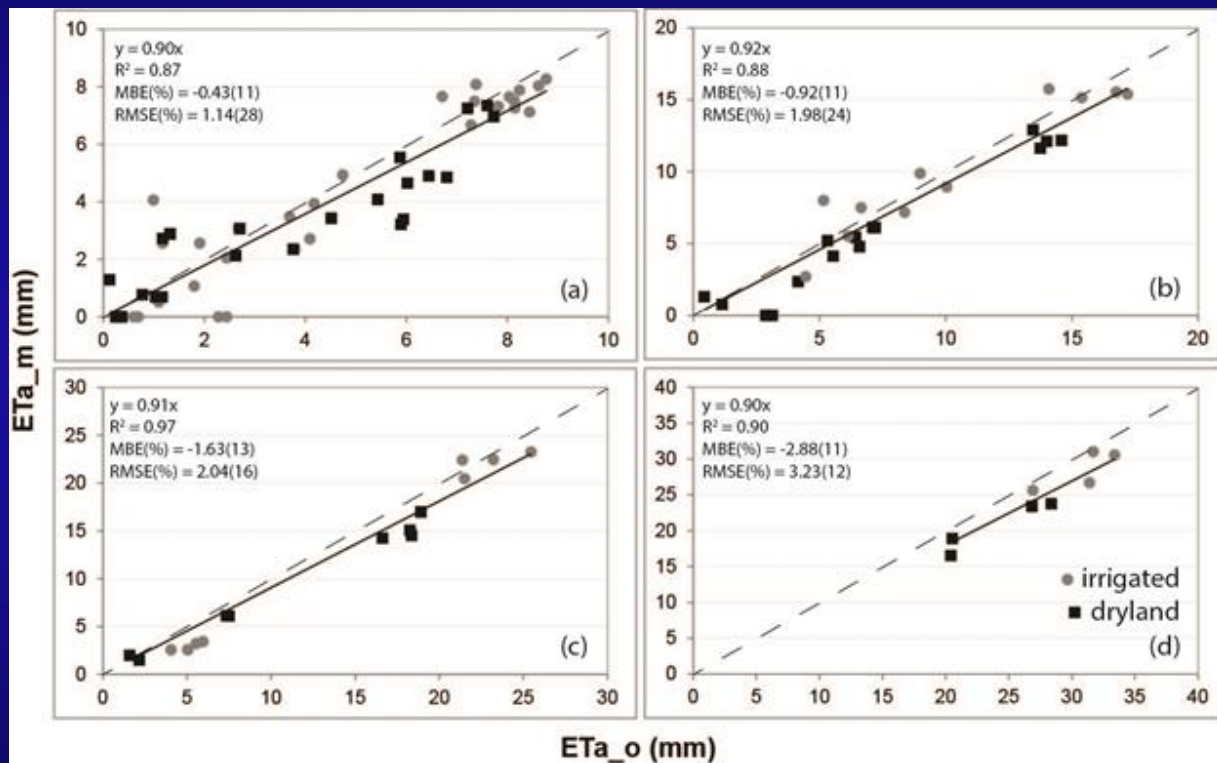
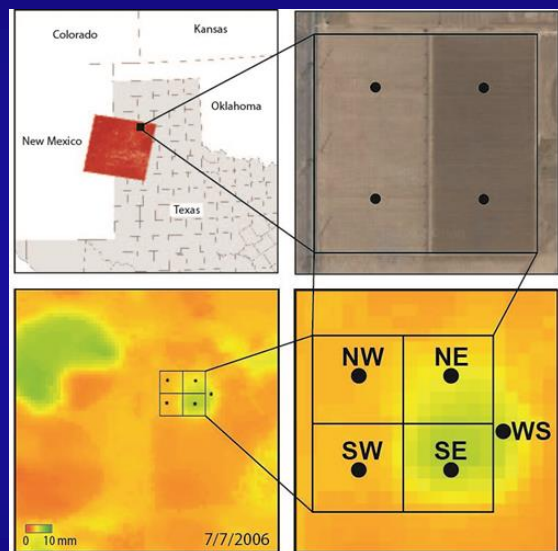
High : 1300

Low : 300



Validation with Lysimeter in Texas High Plains With USDA ARS (P. Gowda)

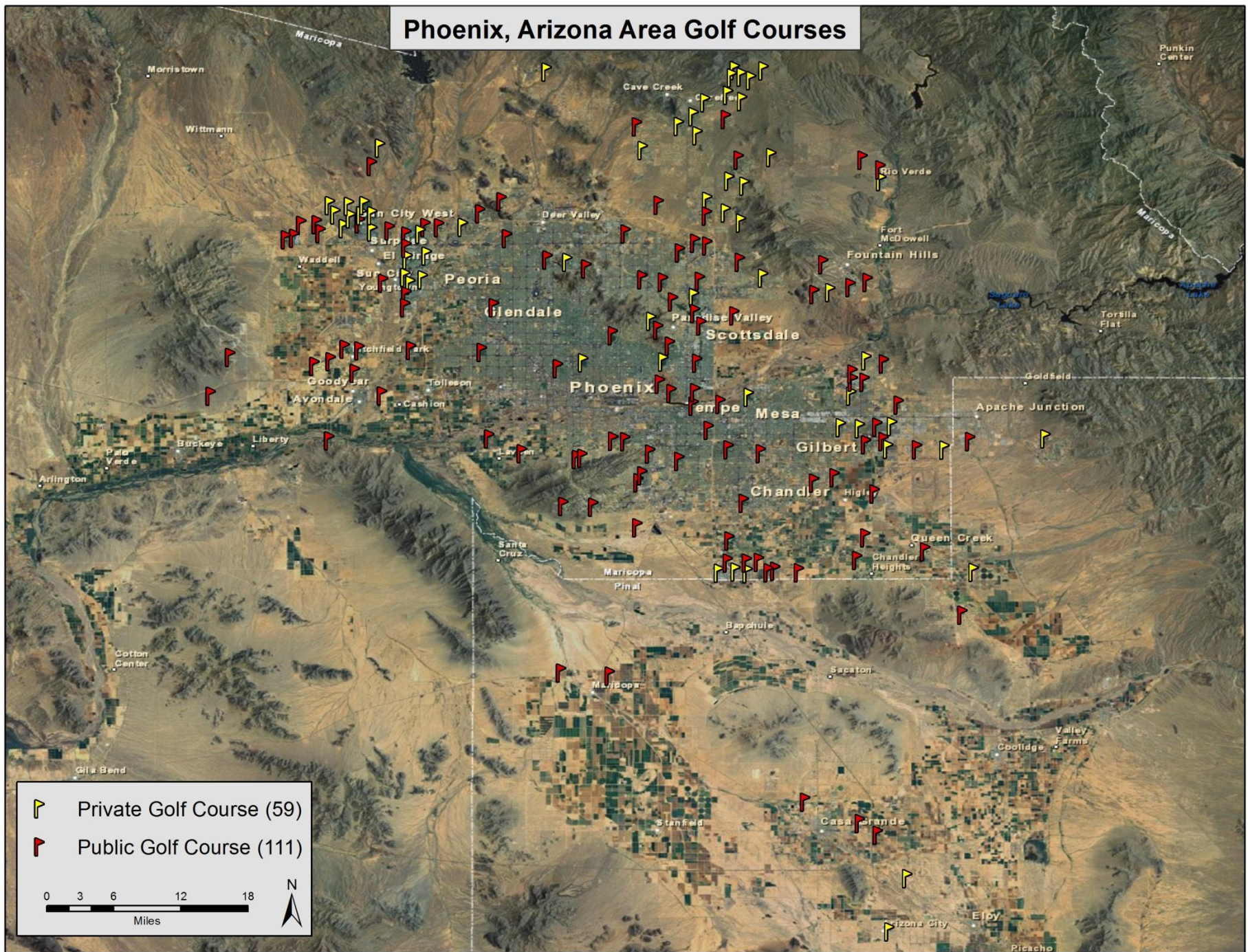
Landsat-based ET using 14 images in 2006-2007



Random error is minimized at
seasonal scale with a seasonal
accuracy of about 90%

Senay et al., 2014. HESSD

Phoenix, Arizona Area Golf Courses



NW Phoenix, Arizona Area Golf Courses

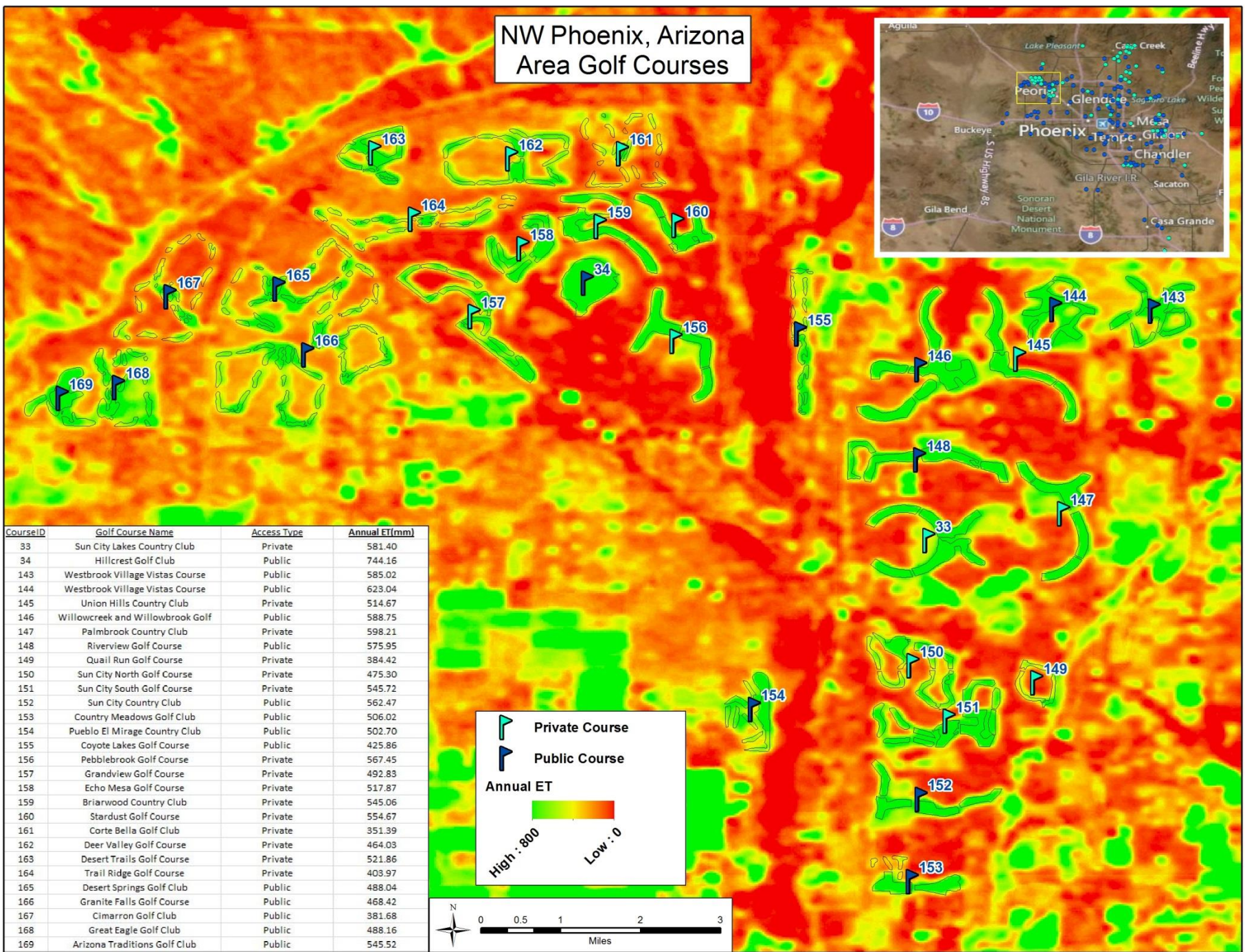


CourseID	Golf Course Name	Access Type	Annual ET(mm)
33	Sun City Lakes Country Club	Private	581.40
34	Hillcrest Golf Club	Public	744.16
143	Westbrook Village Vistas Course	Public	585.02
144	Westbrook Village Vistas Course	Public	623.04
145	Union Hills Country Club	Private	514.67
146	Willowcreek and Willowbrook Golf	Public	588.75
147	Palmbrook Country Club	Private	598.21
148	Riverview Golf Course	Public	575.95
149	Quail Run Golf Course	Private	384.42
150	Sun City North Golf Course	Private	475.30
151	Sun City South Golf Course	Private	545.72
152	Sun City Country Club	Public	562.47
153	Country Meadows Golf Club	Public	506.02
154	Pueblo El Mirage Country Club	Public	502.70
155	Coyote Lakes Golf Course	Public	425.86
156	Pebblebrook Golf Course	Private	567.45
157	Grandview Golf Course	Private	492.83
158	Echo Mesa Golf Course	Private	517.87
159	Briarwood Country Club	Private	545.06
160	Stardust Golf Course	Private	554.67
161	Corte Bella Golf Club	Private	351.39
162	Deer Valley Golf Course	Private	464.03
163	Desert Trails Golf Course	Private	521.86
164	Trail Ridge Golf Course	Private	403.97
165	Desert Springs Golf Club	Public	488.04
166	Granite Falls Golf Course	Public	468.42
167	Cimarron Golf Club	Public	381.68
168	Great Eagle Golf Club	Public	488.16
169	Arizona Traditions Golf Club	Public	545.52

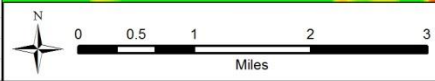
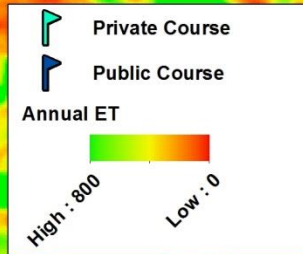
Private Course
Public Course



NW Phoenix, Arizona Area Golf Courses



CourseID	Golf Course Name	Access Type	Annual ET(mm)
33	Sun City Lakes Country Club	Private	581.40
34	Hillcrest Golf Club	Public	744.16
143	Westbrook Village Vistas Course	Public	585.02
144	Westbrook Village Vistas Course	Public	623.04
145	Union Hills Country Club	Private	514.67
146	Willowcreek and Willowbrook Golf	Public	588.75
147	Palmbrook Country Club	Private	598.21
148	Riverview Golf Course	Public	575.95
149	Quail Run Golf Course	Private	384.42
150	Sun City North Golf Course	Private	475.30
151	Sun City South Golf Course	Private	545.72
152	Sun City Country Club	Public	562.47
153	Country Meadows Golf Club	Public	506.02
154	Pueblo El Mirage Country Club	Public	502.70
155	Coyote Lakes Golf Course	Public	425.86
156	Pebblebrook Golf Course	Private	567.45
157	Grandview Golf Course	Private	492.83
158	Echo Mesa Golf Course	Private	517.87
159	Briarwood Country Club	Private	545.06
160	Stardust Golf Course	Private	554.67
161	Corte Bella Golf Club	Private	351.39
162	Deer Valley Golf Course	Private	464.03
163	Desert Trails Golf Course	Private	521.86
164	Trail Ridge Golf Course	Private	403.97
165	Desert Springs Golf Club	Public	488.04
166	Granite Falls Golf Course	Public	468.42
167	Cimarron Golf Club	Public	381.68
168	Great Eagle Golf Club	Public	488.16
169	Arizona Traditions Golf Club	Public	545.52



Conclusion

Remote sensing based ET is reliable enough to provide **timely, consistent and cost effective** monitoring and assessment products for use in:

- **irrigation** water use estimation
- understand basin **water balance** dynamics
- assess and monitor crop performance and **drought**



Team and Contributors

- USGS:
- Jim Verdin
- Jim Rowland
- SGT:
- Stefanie Bohms
- MacKenize Friedrichs
- InuTeg:
- Ramesh Singh
- Manohar Velpuri



Thank you!

